US010008780B2

(12) **United States Patent**
Hosono et al.

(10) **Patent No.: US 10,008,780 B2**
(45) **Date of Patent: Jun. 26, 2018**

(54) **MICROSTRIP ANTENNA**

(71) Applicant: **FUJIKURA LTD.**, Tokyo (JP)

(72) Inventors: **Ryohei Hosono**, Sakura (JP); **Ning Guan**, Sakura (JP); **Yusuke Nakatani**, Sakura (JP)

(73) Assignee: **FUJIKURA LTD.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 182 days.

(21) Appl. No.: **15/121,511**

(22) PCT Filed: **Dec. 10, 2014**

(86) PCT No.: **PCT/JP2014/082688**

§ 371 (c)(1),
(2) Date: **Aug. 25, 2016**

(87) PCT Pub. No.: **WO2015/133033**

PCT Pub. Date: **Sep. 11, 2015**

(65) **Prior Publication Data**

US 2016/0365643 A1 Dec. 15, 2016

(30) **Foreign Application Priority Data**

Mar. 3, 2014 (JP) 2014-040915

(51) **Int. Cl.**

H01Q 13/08	(2006.01)
H01P 5/107	(2006.01)
H01Q 1/38	(2006.01)
H01Q 1/48	(2006.01)
H01P 1/203	(2006.01)

(52) **U.S. Cl.**

CPC ***H01Q 13/08*** (2013.01); ***H01P 5/107*** (2013.01); ***H01Q 1/38*** (2013.01); ***H01Q 1/48*** (2013.01); *H01P 1/2039* (2013.01)

(58) **Field of Classification Search**

CPC H01Q 13/08; H01Q 5/107; H01Q 1/38; H01Q 1/48

USPC .... 343/700 MS

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,291,312 A 9/1981 Kaloi

FOREIGN PATENT DOCUMENTS

JP	4-157905 A	5/1992
JP	9-246852 A	9/1997
JP	2001-111336 A	4/2001
JP	2009-188683 A	8/2009

(Continued)

OTHER PUBLICATIONS

International Search Report dated Feb. 24, 2015, issued in counterpart International Application No. PCT/JP2014/082688 (2 pages).

(Continued)

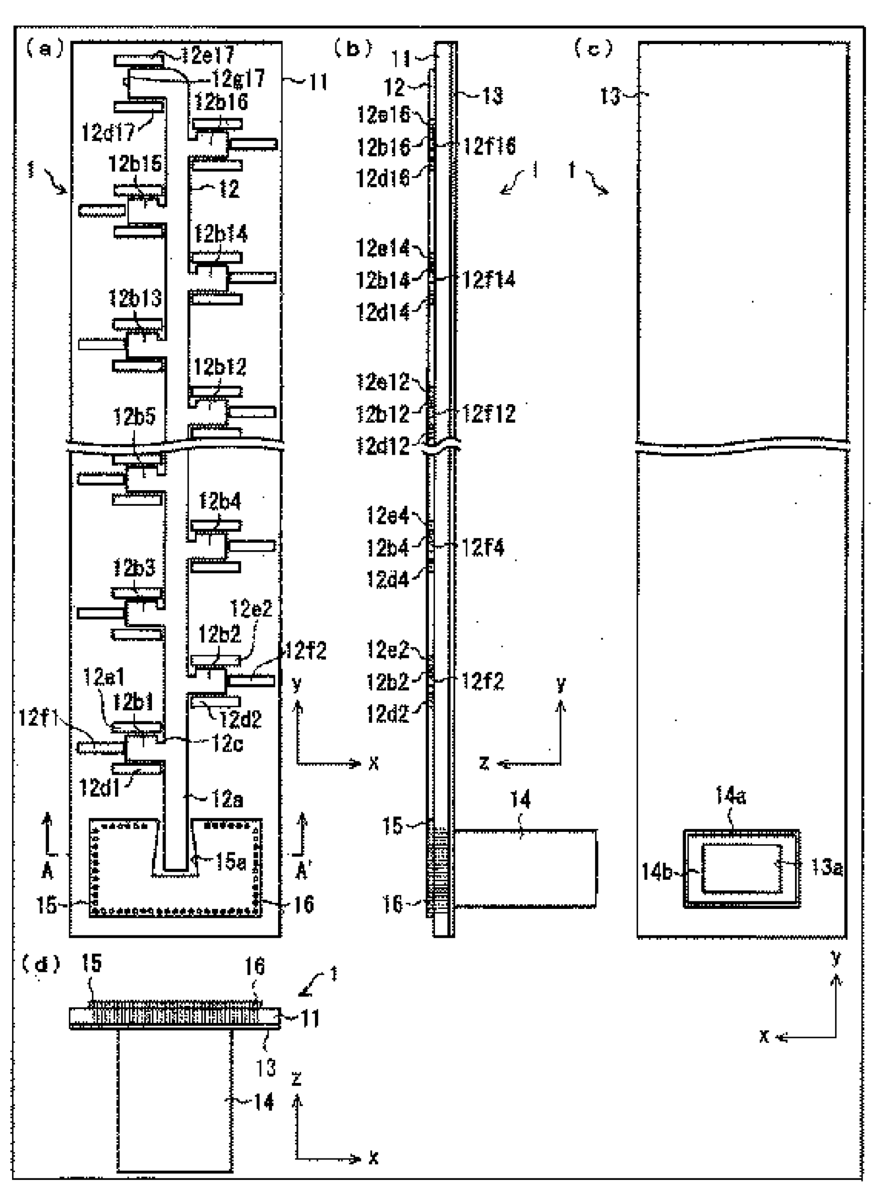
Primary Examiner — Andrea Lindgren Baltzell

(74) *Attorney, Agent, or Firm* — Westerman, Hattori, Daniels & Adrian, LLP

(57) **ABSTRACT**

An antenna (**1**) of the present invention includes: a dielectric substrate (**11**); an antenna conductor (**12**) including: a power feeding line (**12***a*) that extends in a first direction; and a stub (**12***b*); and a ground conductor (**13**). The antenna (**1**) further includes: a first parasitic element (**12***d*) facing a first side of the stub (**12***b*) which first side is on a side of a direction opposite to the first direction; and a second parasitic element (**12***e*) facing a second side of the stub (**12***b*) which second side is on the first direction side.

10 Claims, 28 Drawing Sheets



(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2011-223050 A	11/2011

OTHER PUBLICATIONS

Notice of Reasons for Refusal dated Feb. 17, 2015, issued in counterpart Japanese Patent Application No. 2014-040915 in Japanese (2 pages).

Notice of Allowance dated Jul. 7, 2015, issued in counterpart Japanese Patent Application No. 2014-040915 in Japanese (1 page).

FIG. 1

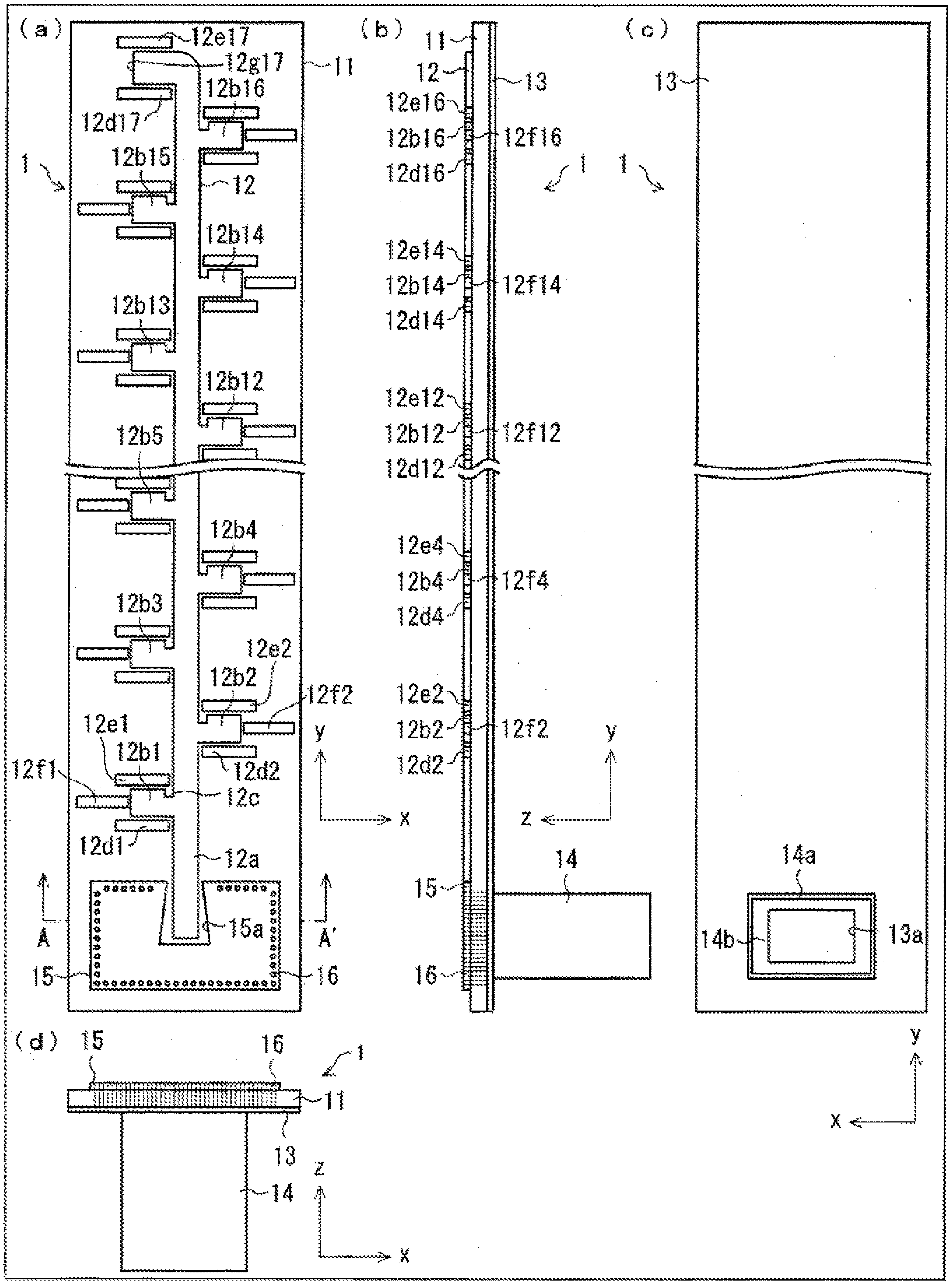

(a)
12e17
12g17
11
12b16
12d17
1
12b15
12
12b14
12b13
12b12
12b5
12b4
12b3
12e2
12b2
12f2
12e1
12b1
12f1
12d2
12c
12d1
12a
A
15a
A'
15
16
y
x
(b)
11
12
13
12e16
12b16
12f16
12d16
12e14
12b14
12f14
12d14
12e12
12b12
12f12
12d12
12e4
12b4
12f4
12d4
12e2
12b2
12f2
12d2
z
14
(c)
14a
14b
13a
(d)
z

FIG. 2

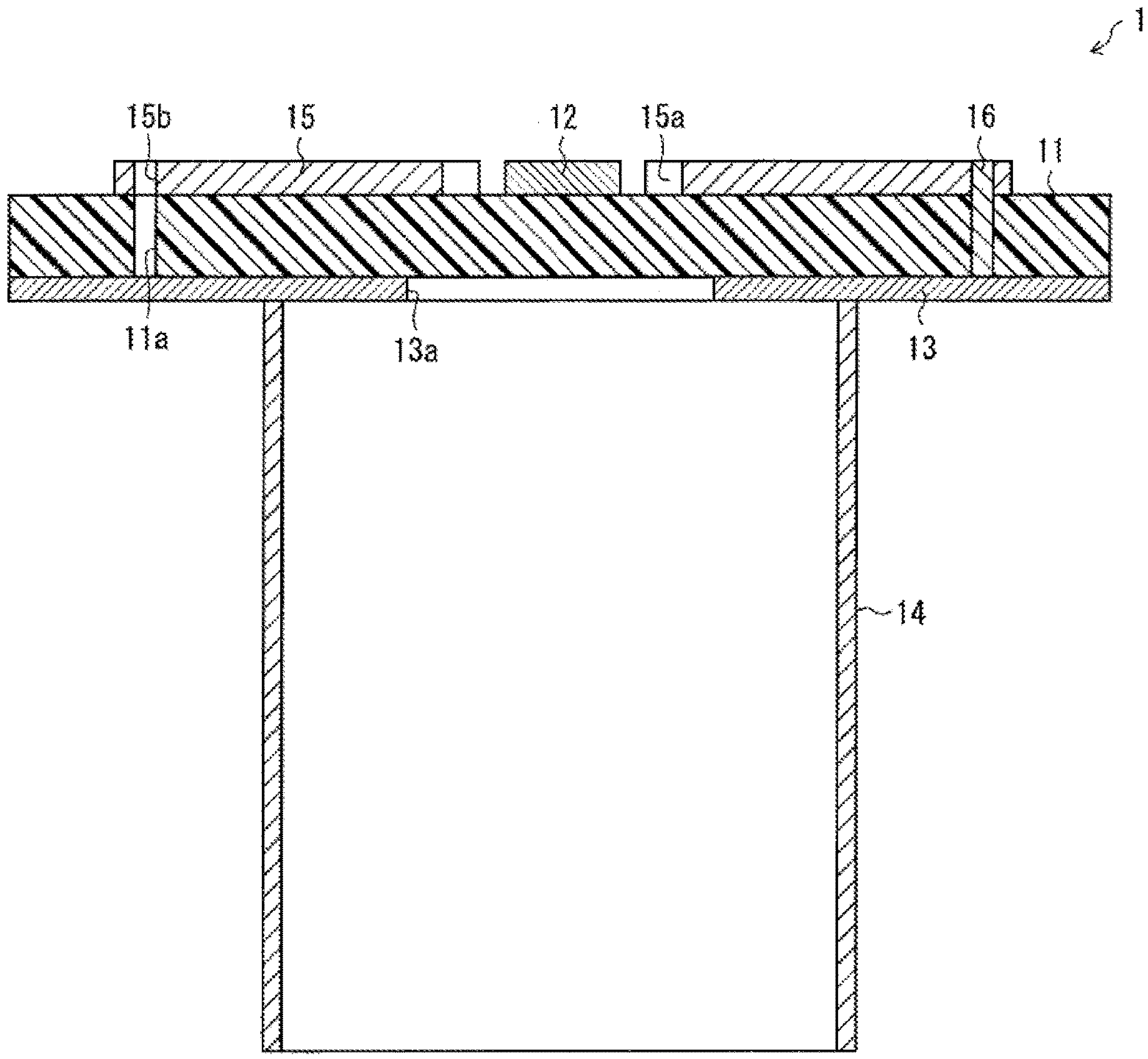


FIG. 3

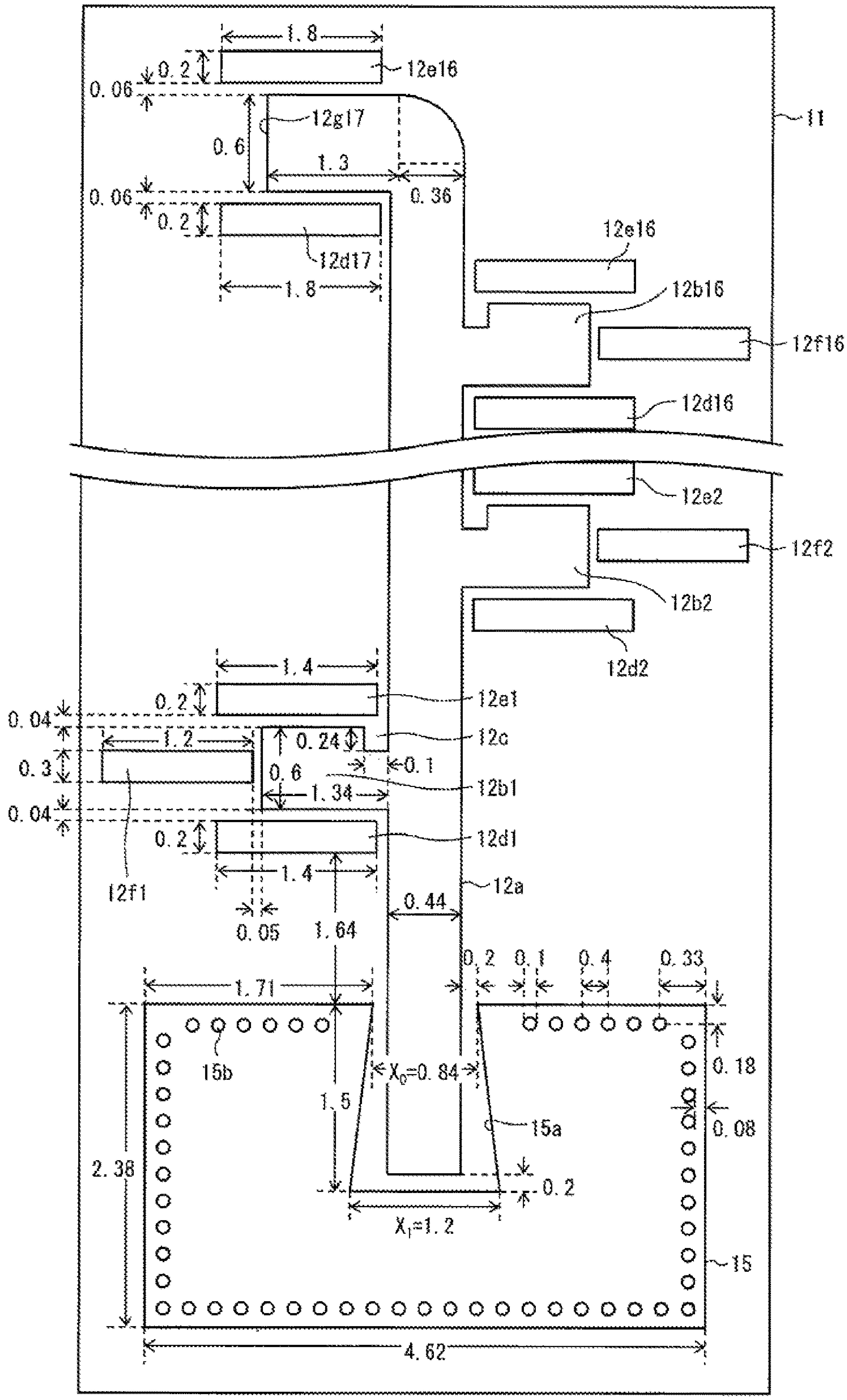

1
11
1.8
0.2
12e16
0.06
12g17
0.6
1.3
0.36
0.06
0.2
12d17
1.8
12e16
12b16
12f16
12d16
12e2
12f2
12b2
12d2
1.4
0.2
12e1
0.04
1.2
0.24
12c
0.3
0.1
0.6
12b1
1.34
0.04
0.2
12d1
1.4
12a
12f1
0.44
0.05
1.64
0.2
0.1
0.4
0.33
1.71
15b
0.18
X_0=0.84
1.5
15a
0.08
2.38
0.2
X_1=1.2
15
4.62

FIG. 4

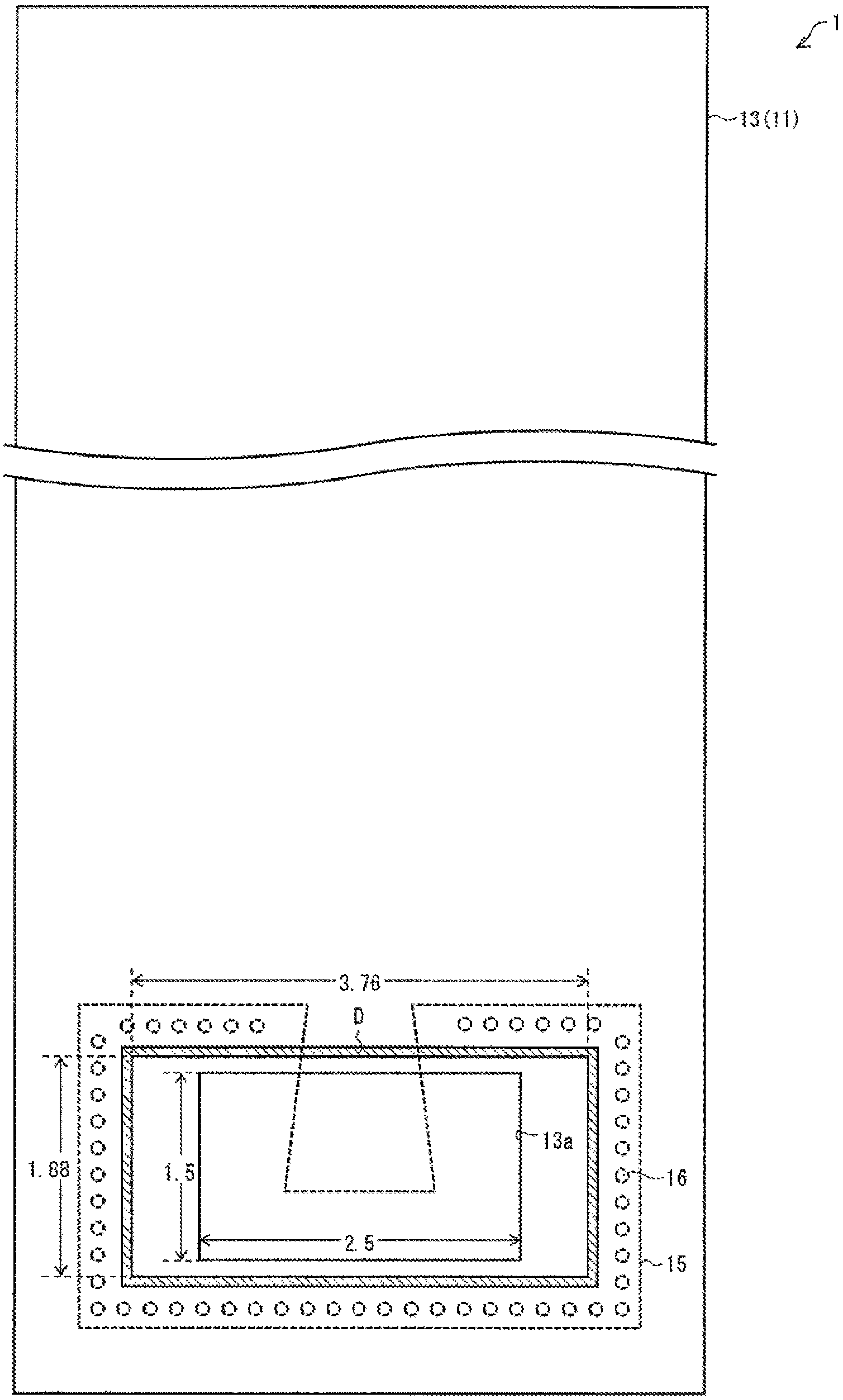


FIG. 5

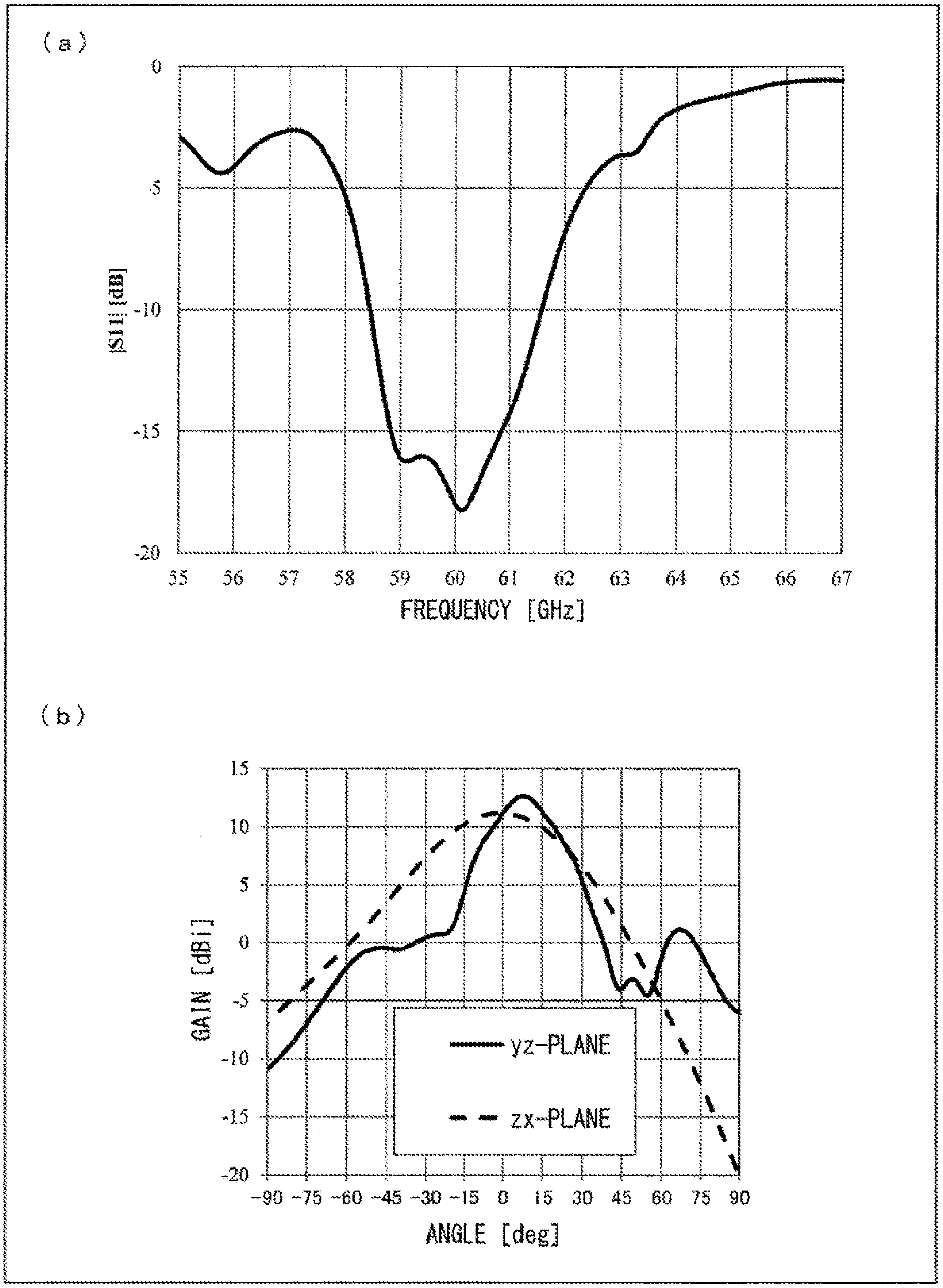

(a)
|S11| [dB]
0
-5
-10
-15
-20
55 56 57 58 59 60 61 62 63 64 65 66 67
FREQUENCY [GHz]
(b)
GAIN [dBi]
15
10
5
0
-5
-10
-15
-20
−90 −75 −60 −45 −30 −15 0 15 30 45 60 75 90
ANGLE [deg]
yz-PLANE
zx-PLANE

FIG. 6

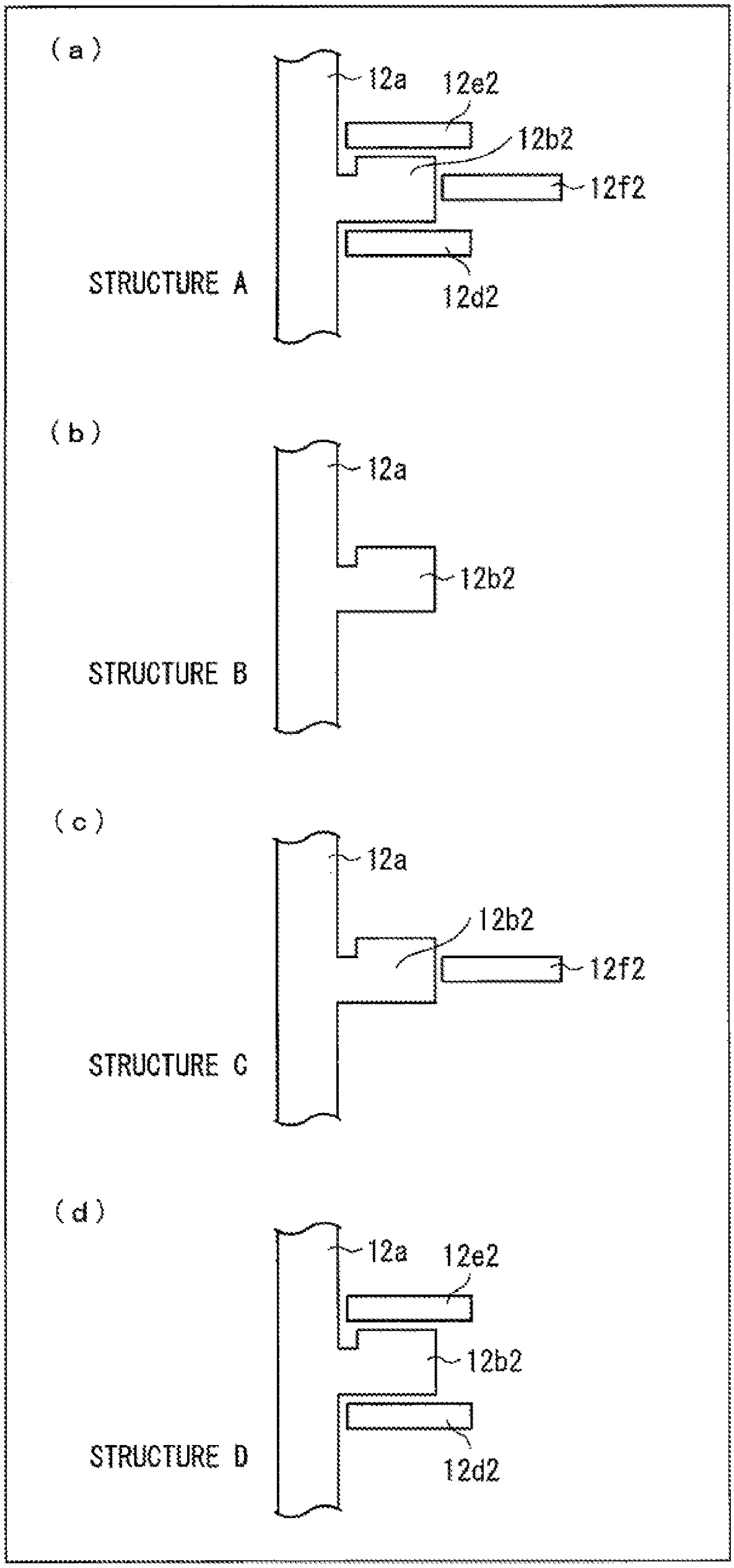

(a)
12a
12e2
12b2
12f2
STRUCTURE A
12d2
(b)
12a
12b2
STRUCTURE B
(c)
12a
12b2
12f2
STRUCTURE C
(d)
12a
12e2
12b2
STRUCTURE D
12d2

FIG. 7

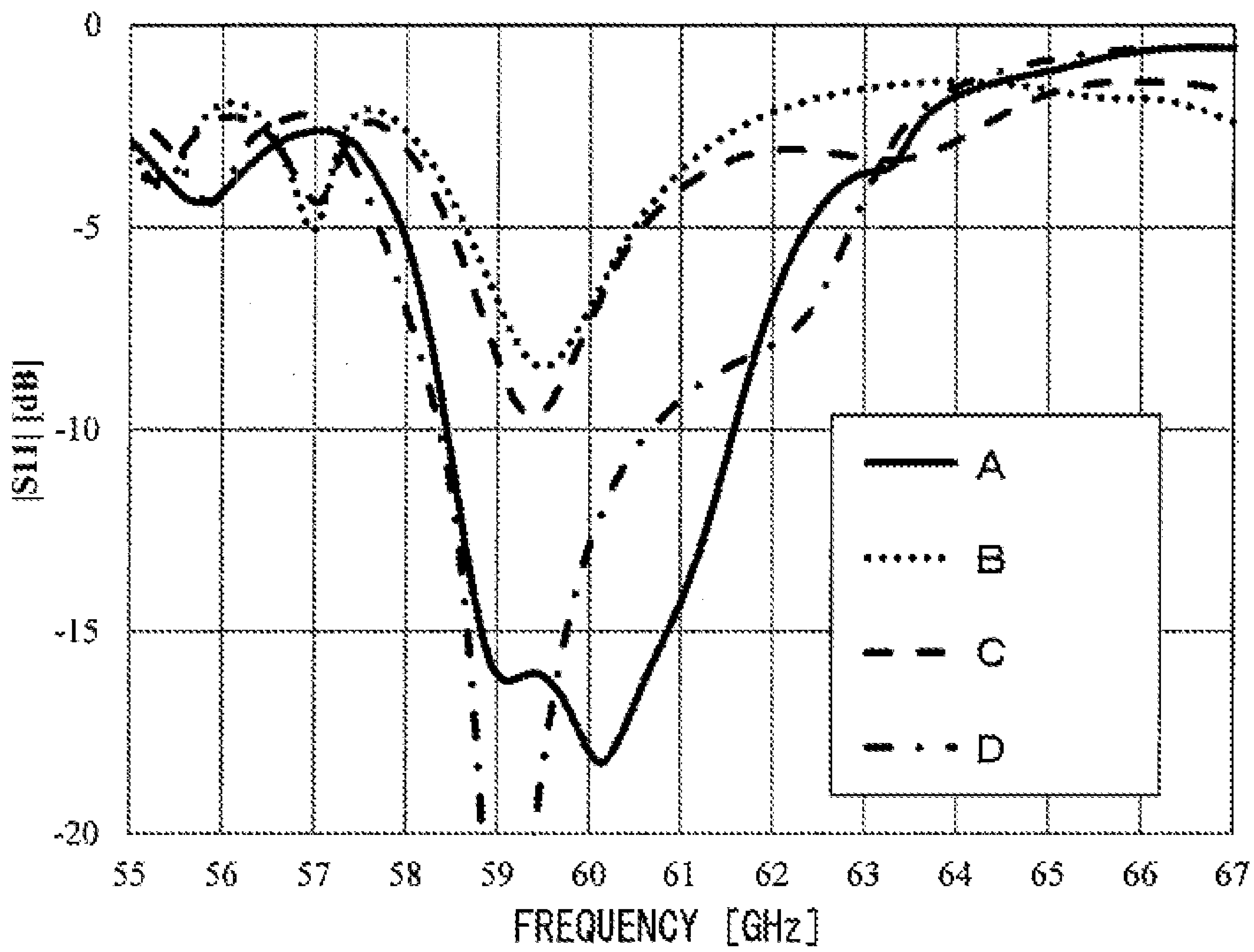

0
-5
-10
-15
-20
|S11| [dB]
55
56
57
58
59
60
61
62
63
64
65
66
67
FREQUENCY [GHz]
A
B
C
D

FIG. 8

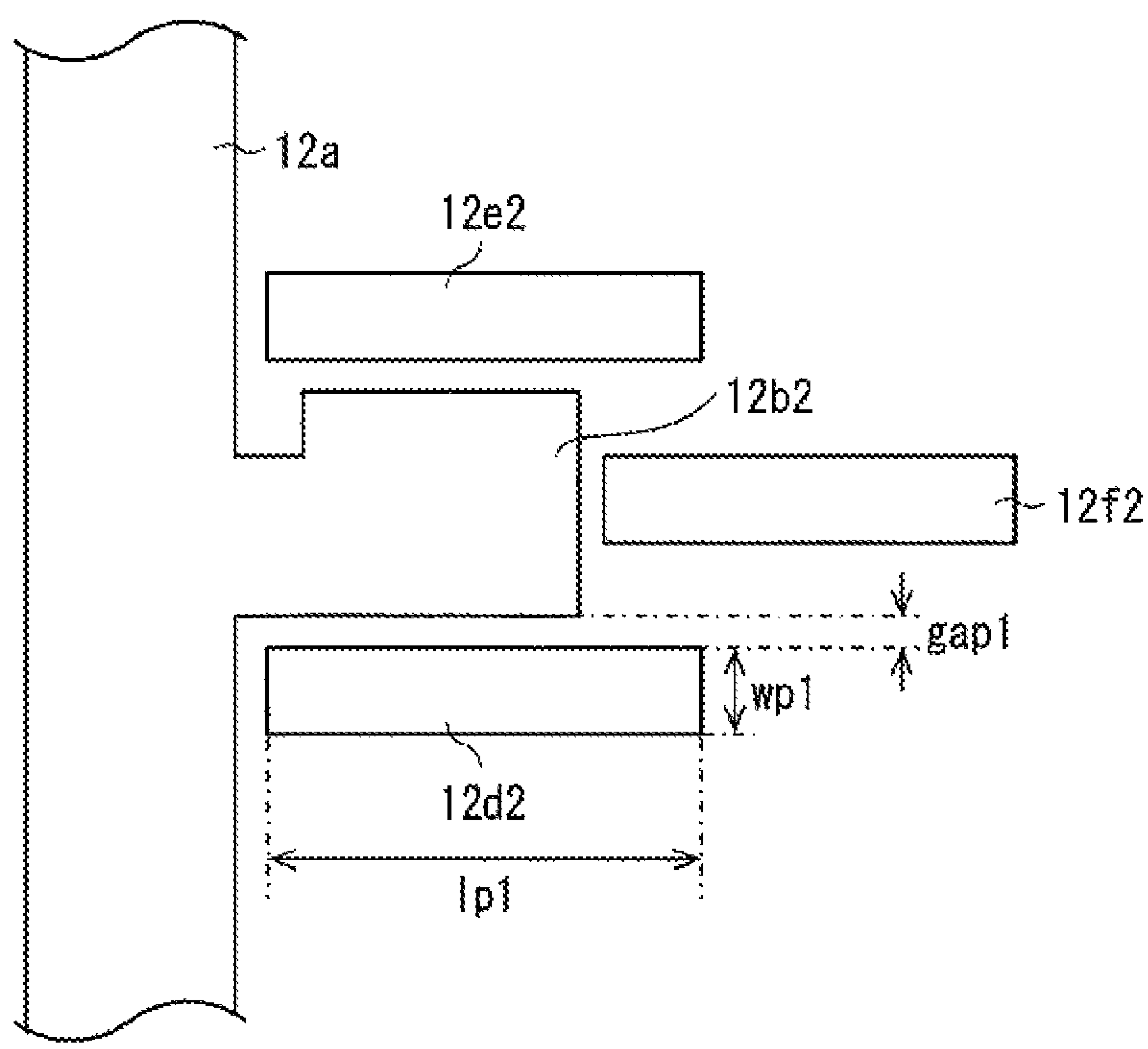

12a
12e2
12b2
12f2
gap1
wp1
12d2
lp1

FIG. 9

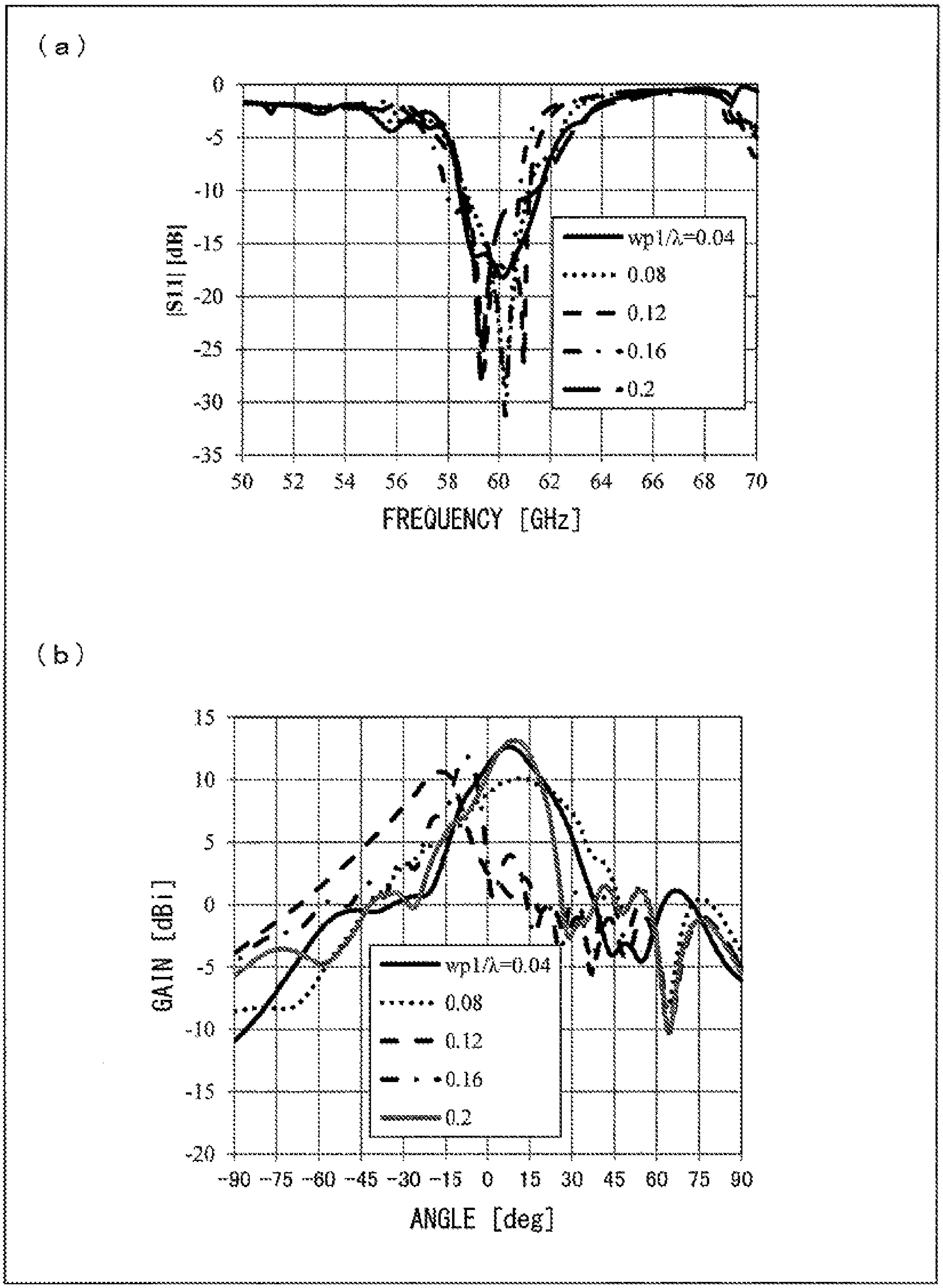

(a)
0
-5
-10
-15
-20
-25
-30
-35
|S11| [dB]
50 52 54 56 58 60 62 64 66 68 70
FREQUENCY [GHz]
wp1/λ=0.04
0.08
0.12
0.16
0.2
(b)
15
10
5
0
-5
-10
-15
-20
GAIN [dBi]
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE [deg]
wp1/λ=0.04
0.08
0.12
0.16
0.2

FIG. 10

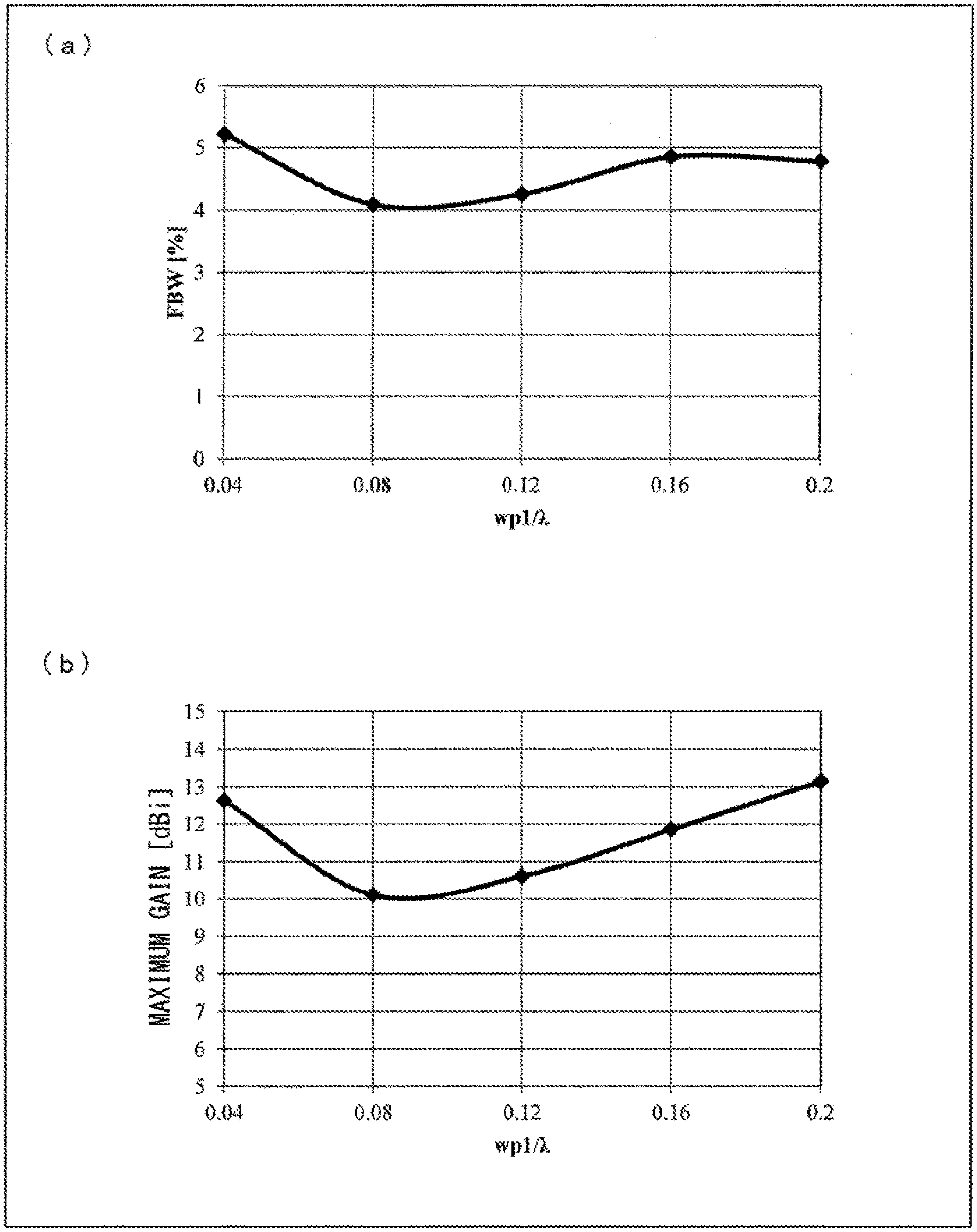
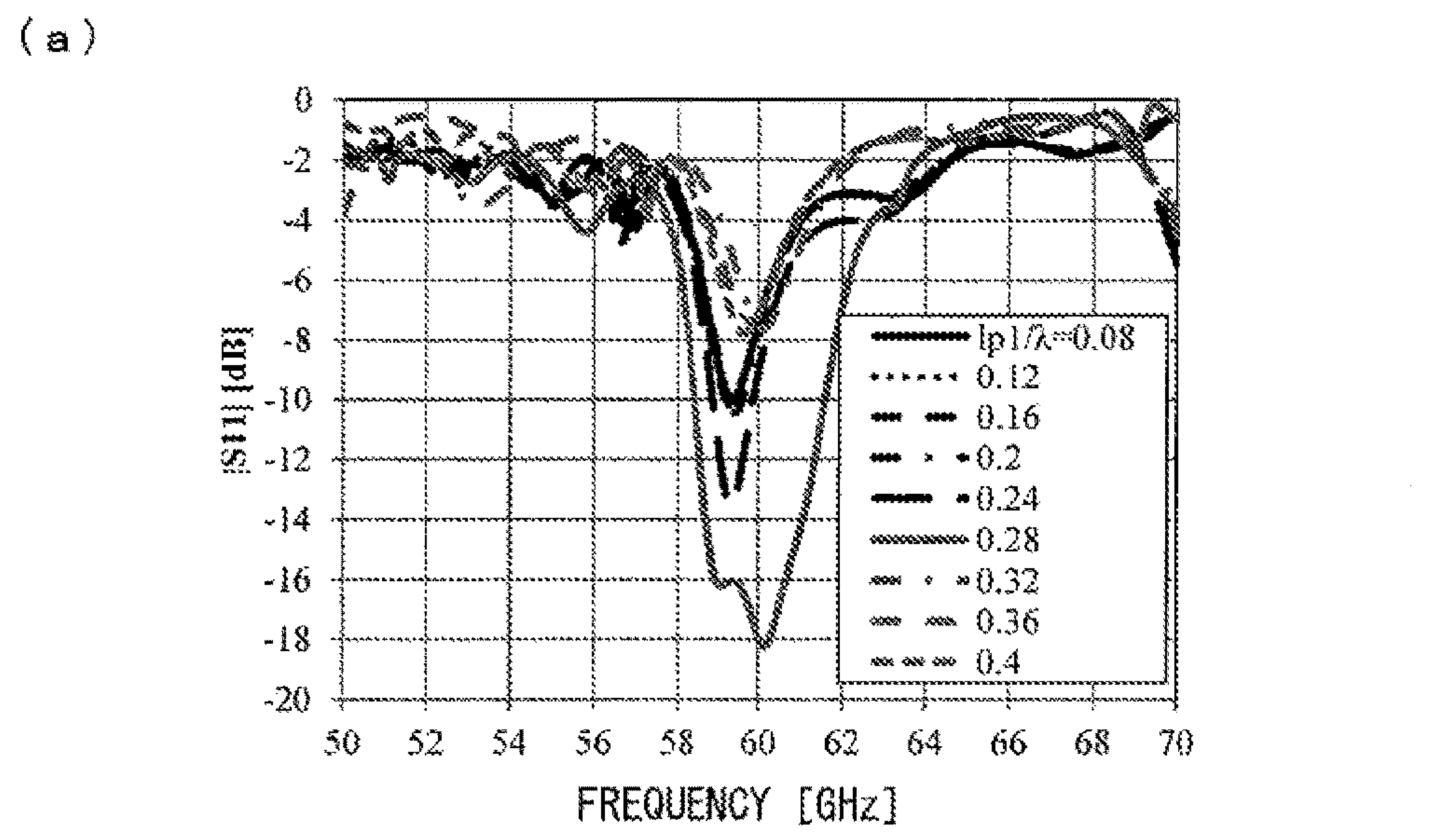

(a)
FBW [%]
0
1
2
3
4
5
6
0.04
0.08
0.12
0.16
0.2
wp1/λ
(b)
MAXIMUM GAIN [dBi]
5
6
7
8
9
10
11
12
13
14
15
0.04
0.08
0.12
0.16
0.2
wp1/λ

FIG. 11


(a)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
|S11| [dB]
50 52 54 56 58 60 62 64 66 68 70
FREQUENCY [GHz]
lp1/λ=0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4

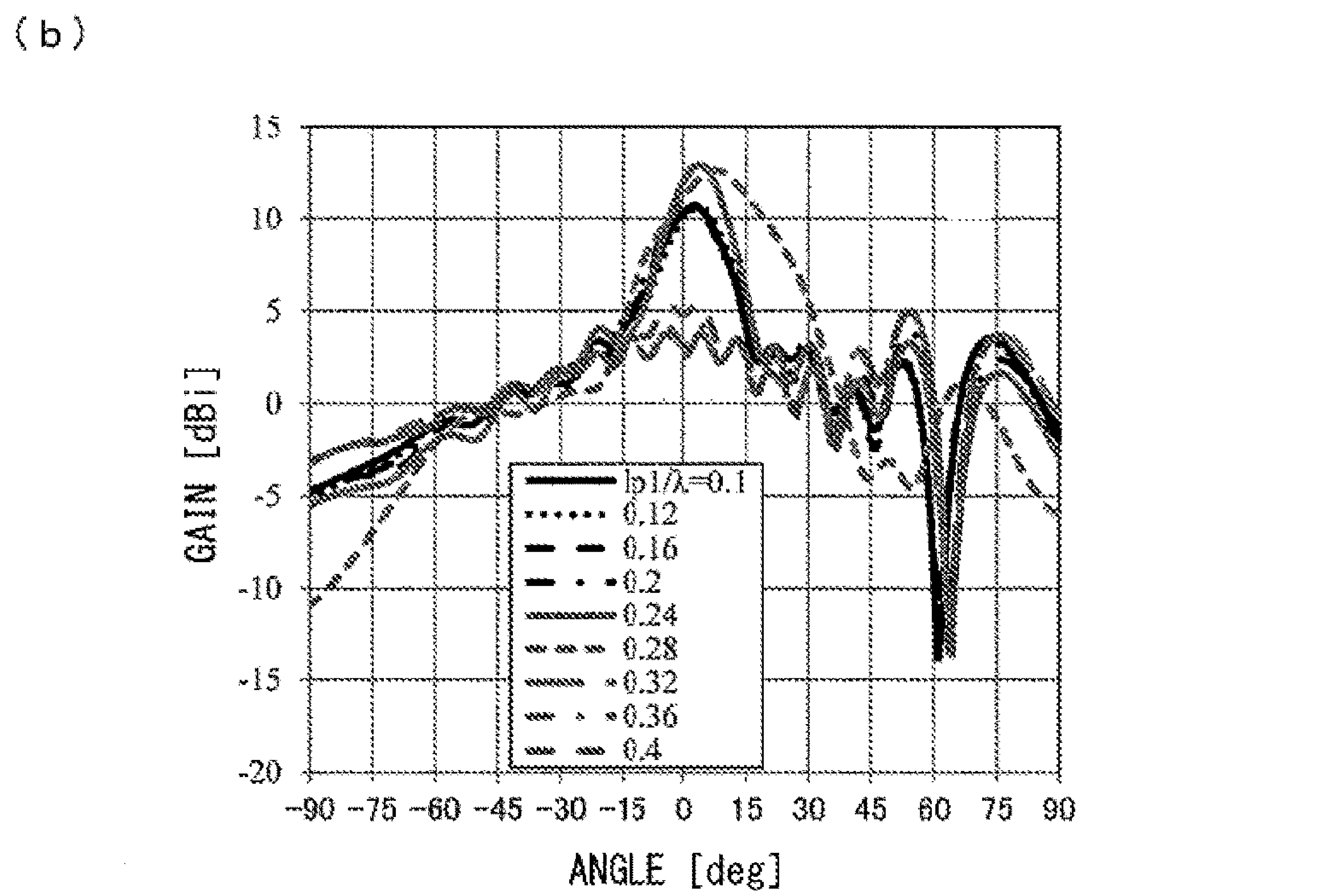
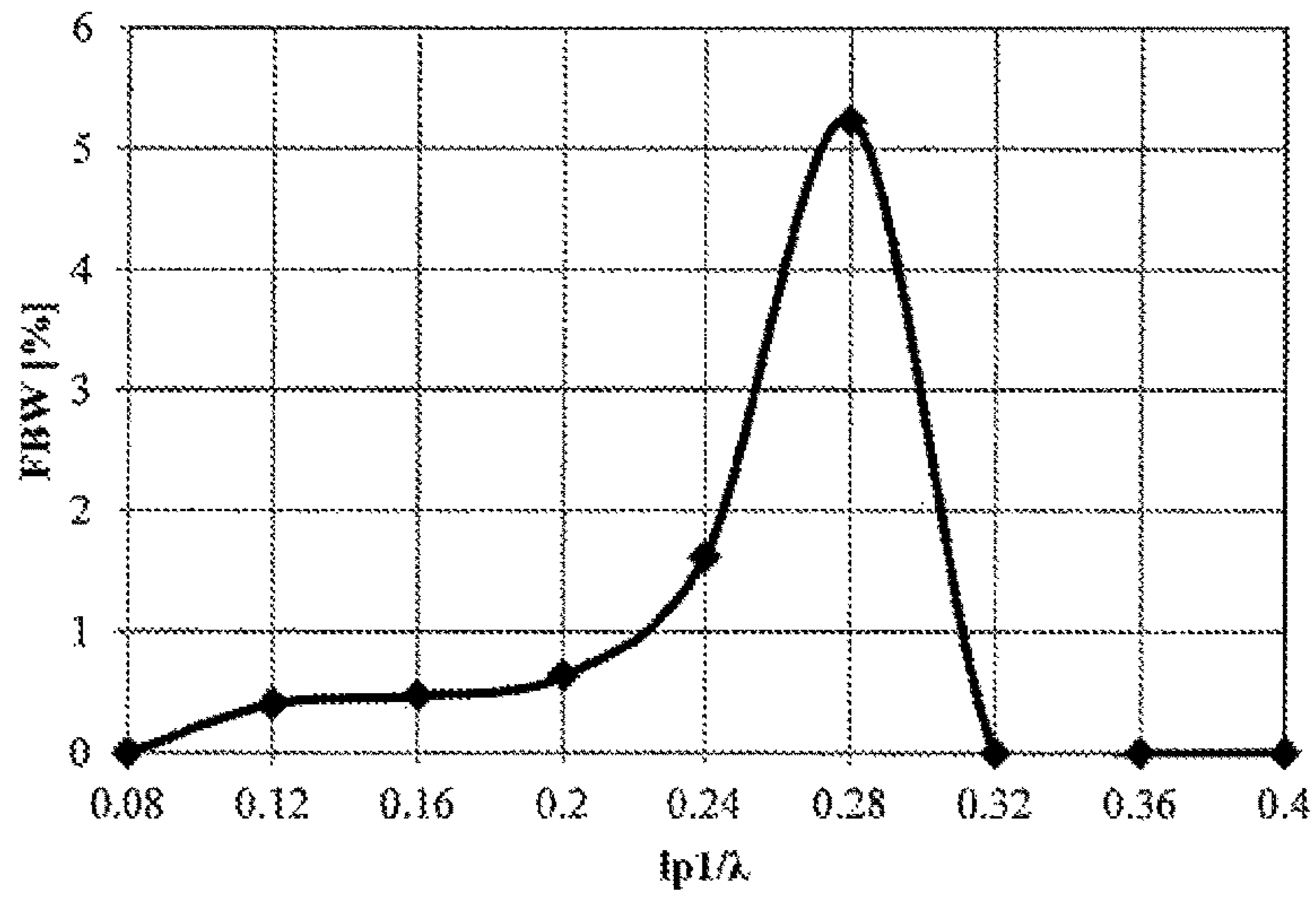

(b)
15
10
5
0
-5
-10
-15
-20
GAIN [dBi]
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE [deg]
lp1/λ=0.1
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4

FIG. 12

(a)


FBW [%]
6
5
4
3
2
1
0
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
lp1/λ

(b)

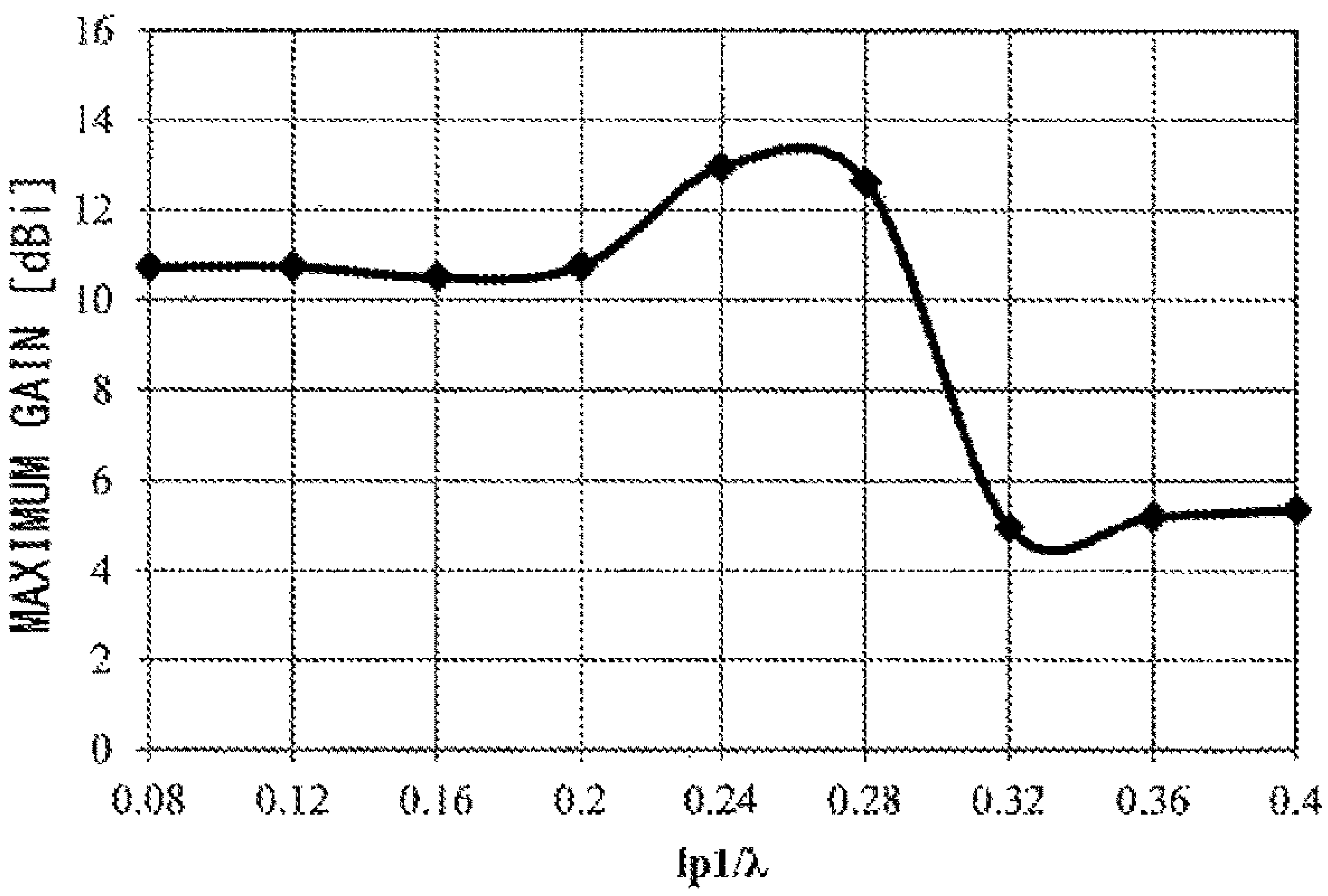

MAXIMUM GAIN [dBi]
16
14
12
10
8
6
4
2
0
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
lp1/λ

FIG. 13

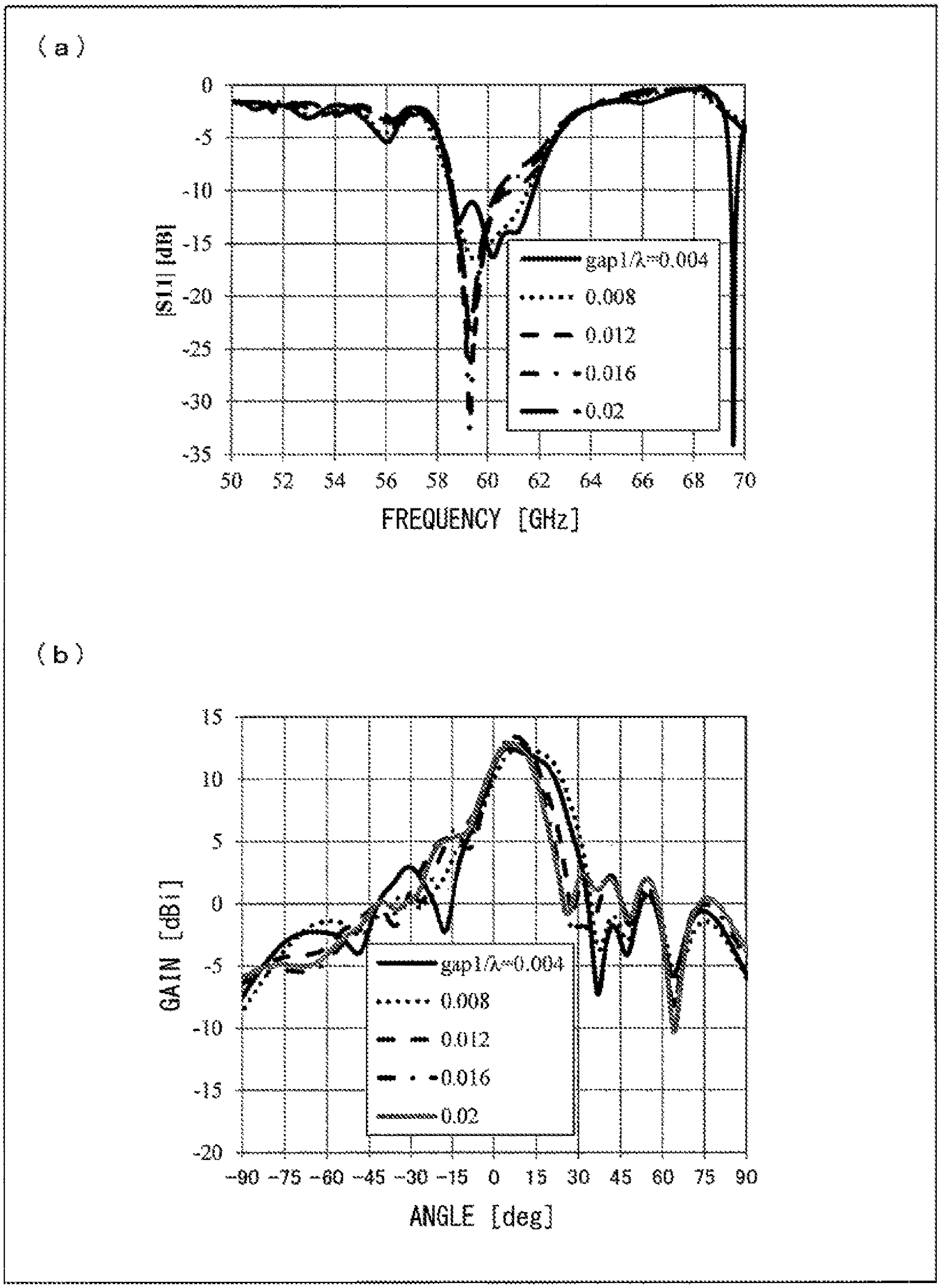
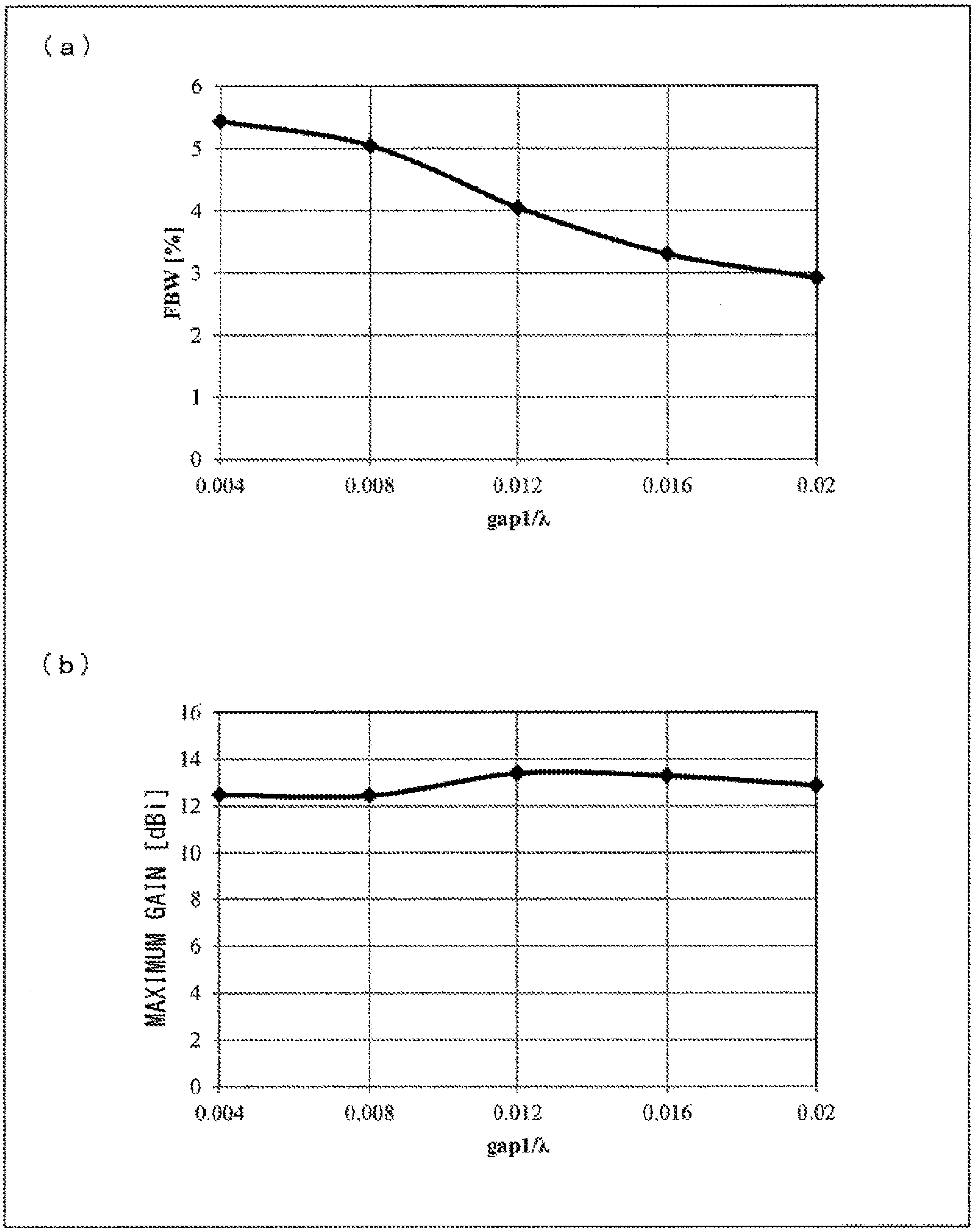

(a)
0
-5
-10
-15
-20
-25
-30
-35
|S11| [dB]
50 52 54 56 58 60 62 64 66 68 70
FREQUENCY [GHz]
gap1/λ=0.004
0.008
0.012
0.016
0.02
(b)
15
10
5
0
-5
-10
-15
-20
GAIN [dBi]
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE [deg]
gap1/λ=0.004
0.008
0.012
0.016
0.02

FIG. 14



(a)
6
5
4
3
2
1
0
FBW [%]
0.004
0.008
0.012
0.016
0.02
gap1/λ
(b)
16
14
12
10
8
6
4
2
0
MAXIMUM GAIN [dBi]
0.004
0.008
0.012
0.016
0.02
gap1/λ

FIG. 15

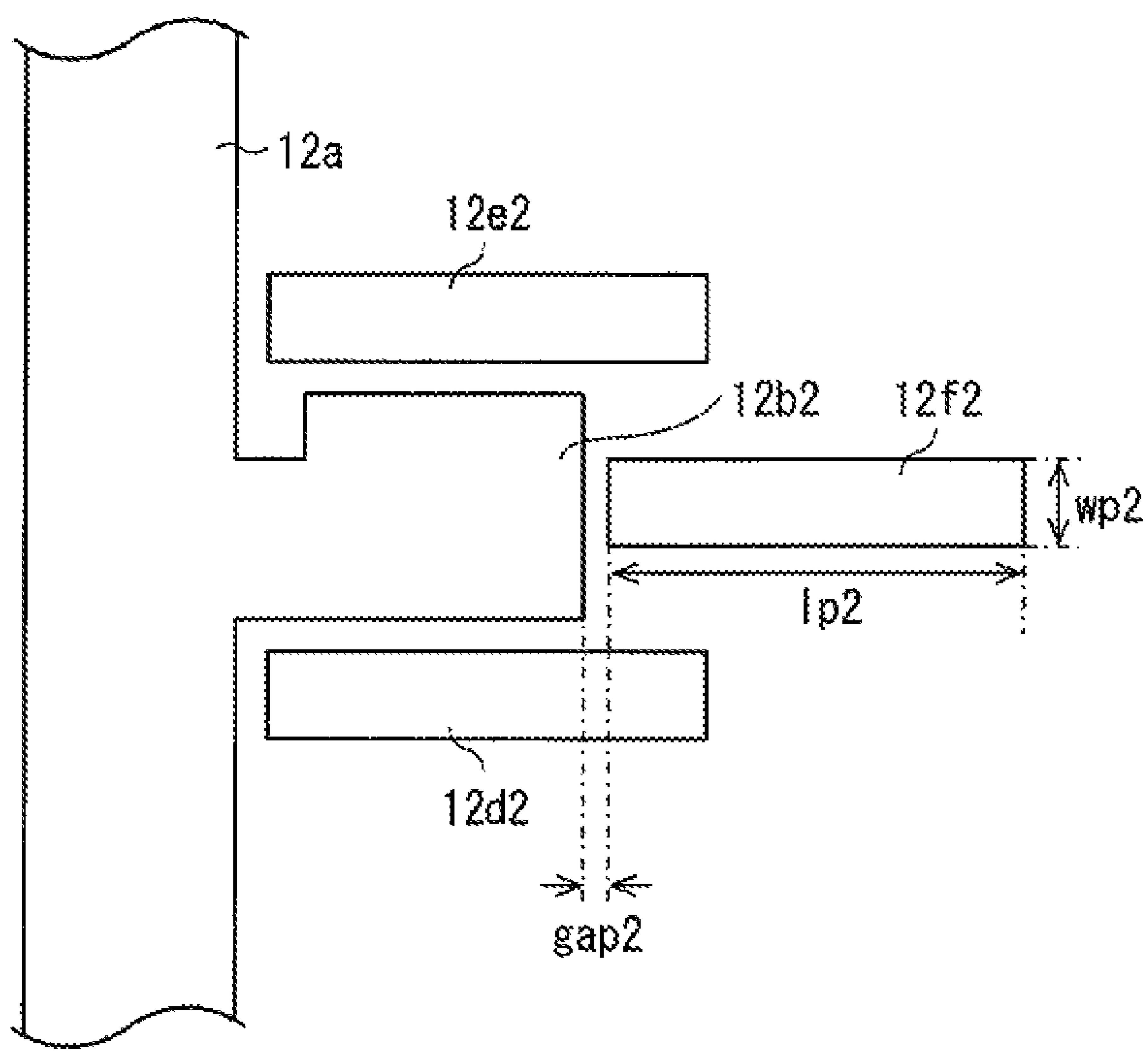


FIG. 16

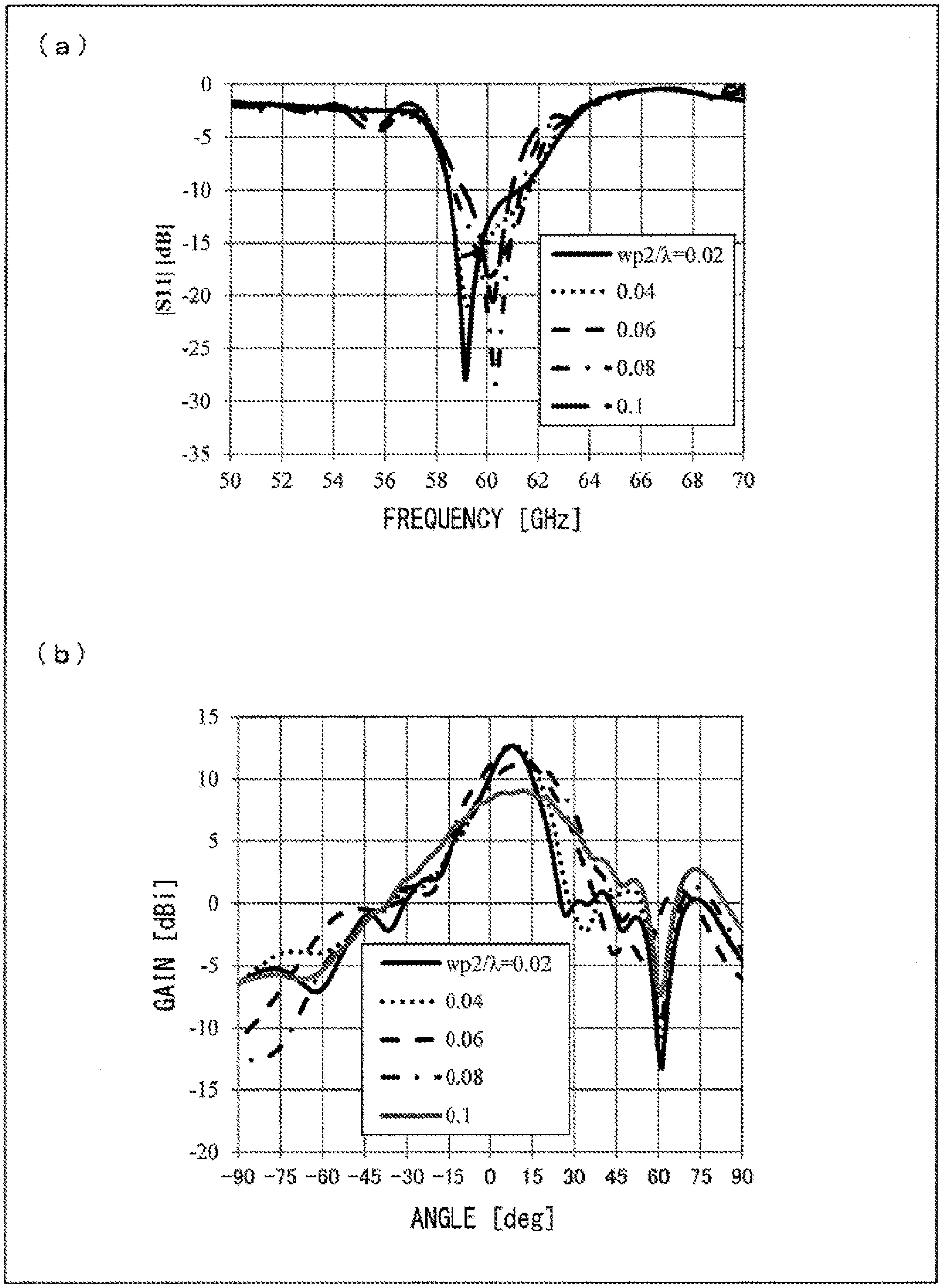

(a)
0
-5
-10
-15
-20
-25
-30
-35
|S11| [dB]
50
52
54
56
58
60
62
64
66
68
70
FREQUENCY [GHz]
wp2/λ=0.02
0.04
0.06
0.08
0.1
(b)
15
10
5
0
-5
-10
-15
-20
GAIN [dBi]
-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90
ANGLE [deg]
wp2/λ=0.02
0.04
0.06
0.08
0.1

FIG. 17

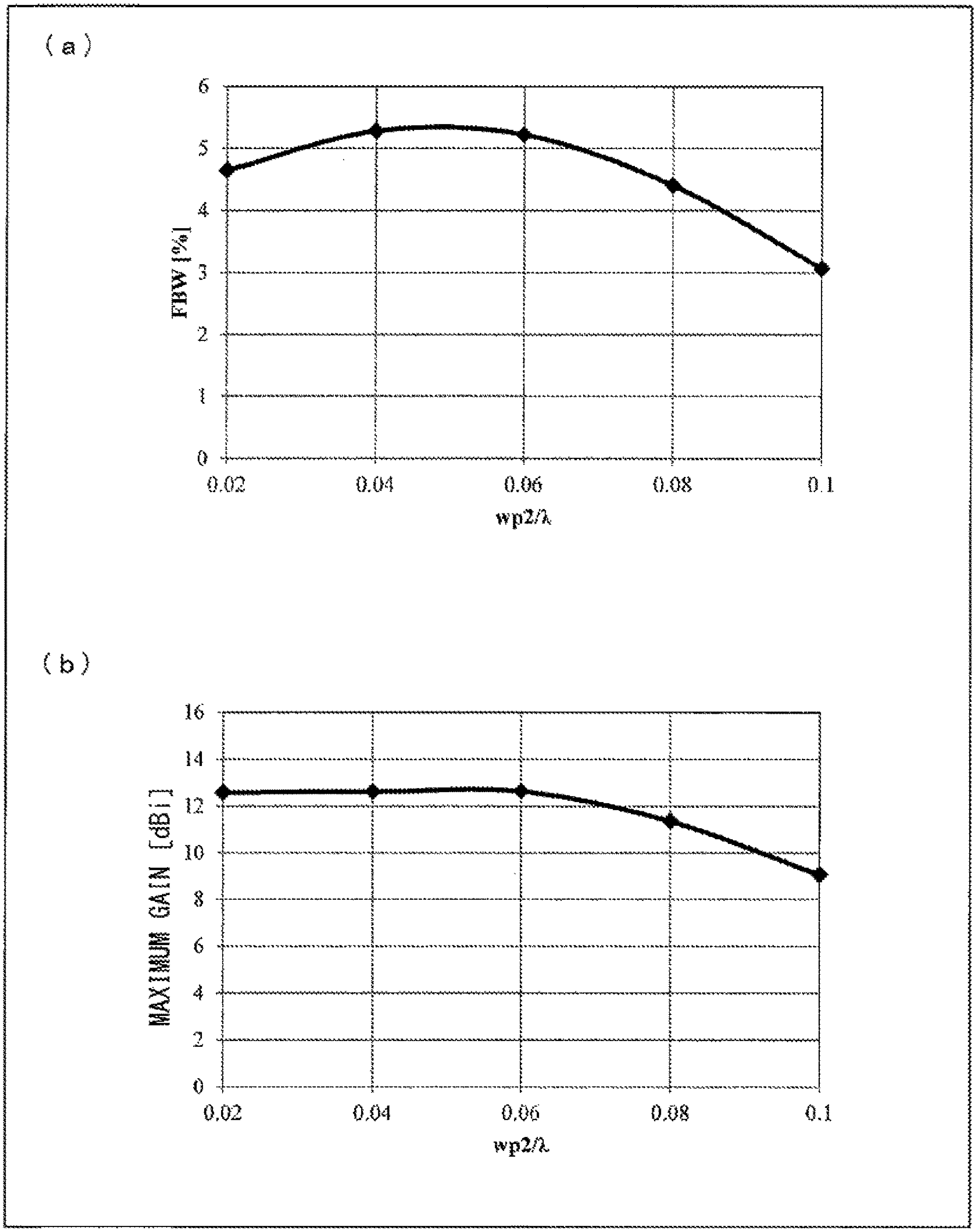
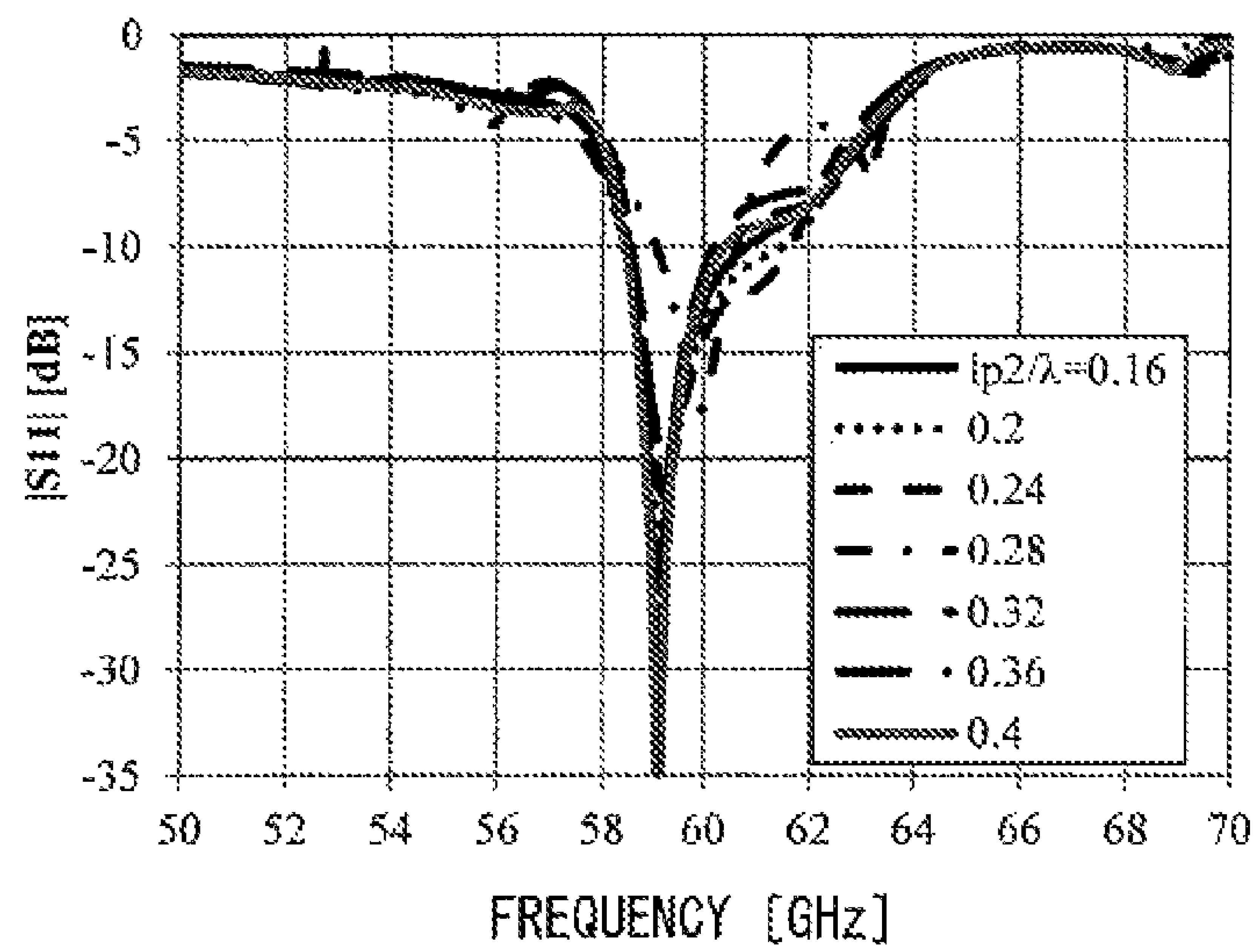

(a)
FBW [%]
6
5
4
3
2
1
0
0.02
0.04
0.06
0.08
0.1
wp2/λ
(b)
MAXIMUM GAIN [dBi]
16
14
12
10
8
6
4
2
0
0.02
0.04
0.06
0.08
0.1
wp2/λ

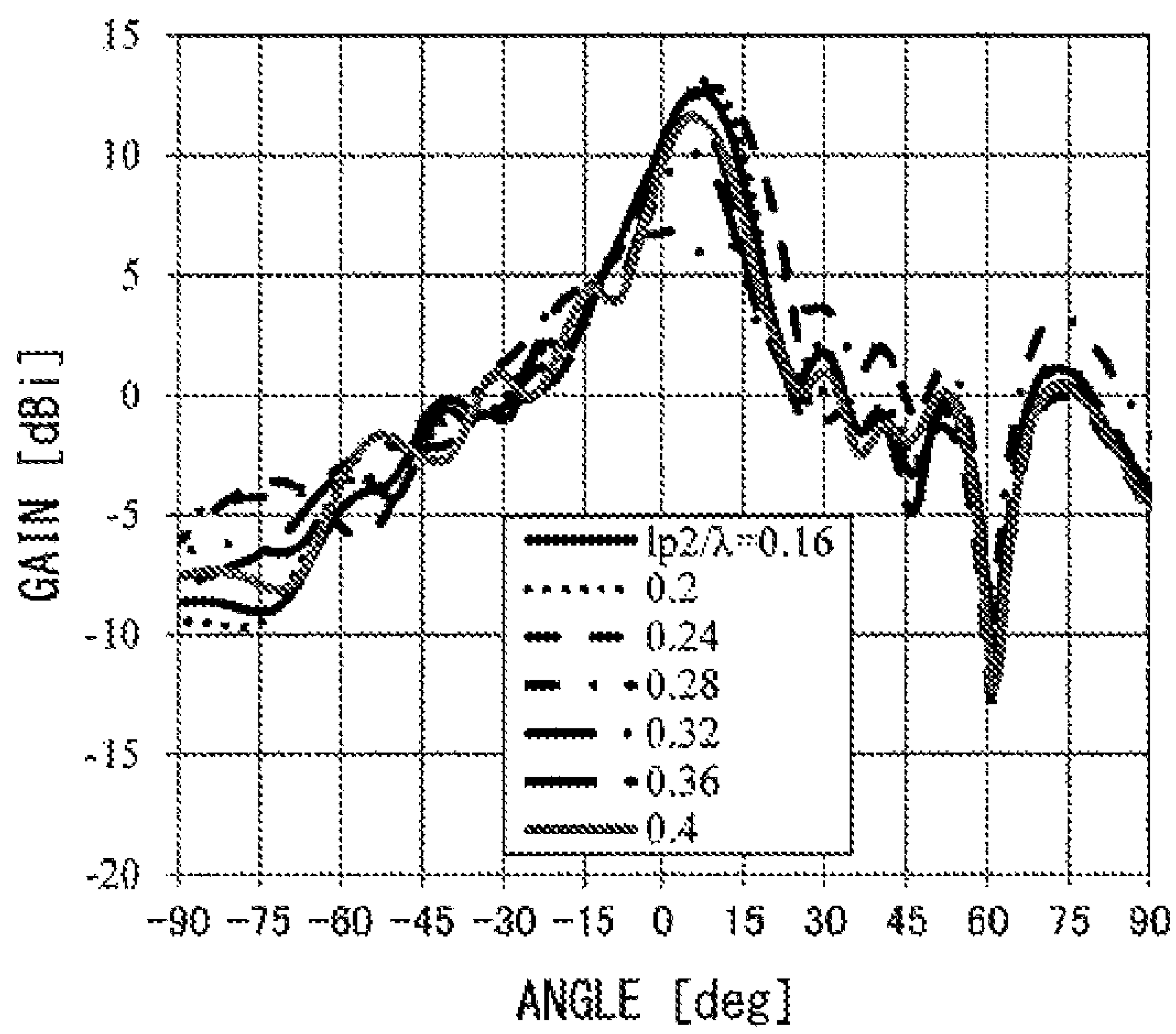
FIG. 18

(a)



0
-5
-10
-15
-20
-25
-30
-35
|S11| [dB]
50
52
54
56
58
60
62
64
66
68
70
FREQUENCY [GHz]
lp2/λ=0.16
0.2
0.24
0.28
0.32
0.36
0.4

(b)



15
10
5
0
-5
-10
-15
-20
GAIN [dBi]
-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90
ANGLE [deg]
lp2/λ=0.16
0.2
0.24
0.28
0.32
0.36
0.4

FIG. 19

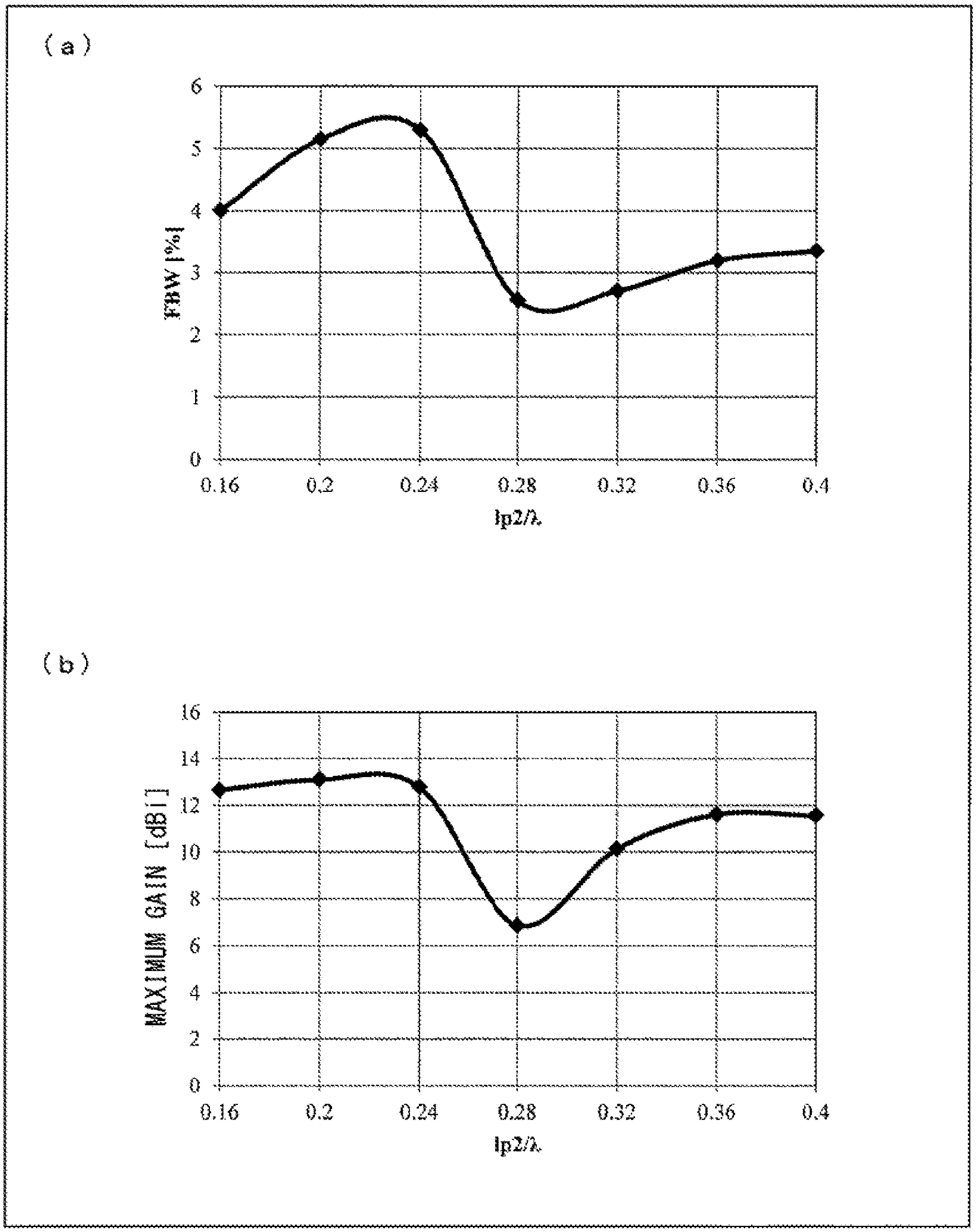

(a)
6
5
4
3
2
1
0
FBW [%]
0.16
0.2
0.24
0.28
0.32
0.36
0.4
lp2/λ
(b)
16
14
12
10
8
6
4
2
0
MAXIMUM GAIN [dBi]
0.16
0.2
0.24
0.28
0.32
0.36
0.4
lp2/λ

FIG. 20

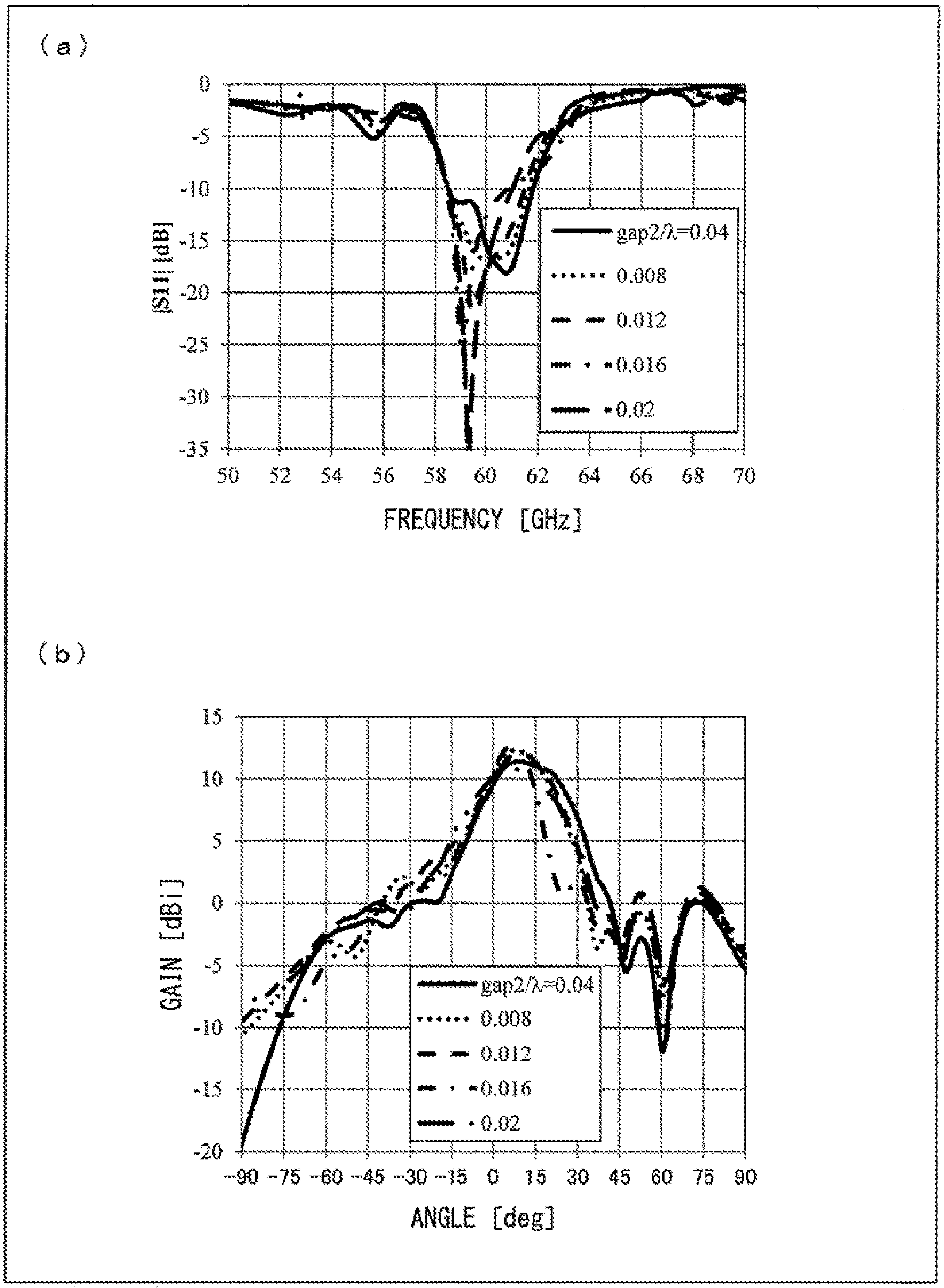

(a)
0
-5
-10
-15
-20
-25
-30
-35
|S11| [dB]
50 52 54 56 58 60 62 64 66 68 70
FREQUENCY [GHz]
gap2/λ=0.04
0.008
0.012
0.016
0.02
(b)
15
10
5
0
-5
-10
-15
-20
GAIN [dBi]
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE [deg]
gap2/λ=0.04
0.008
0.012
0.016
0.02

FIG. 21

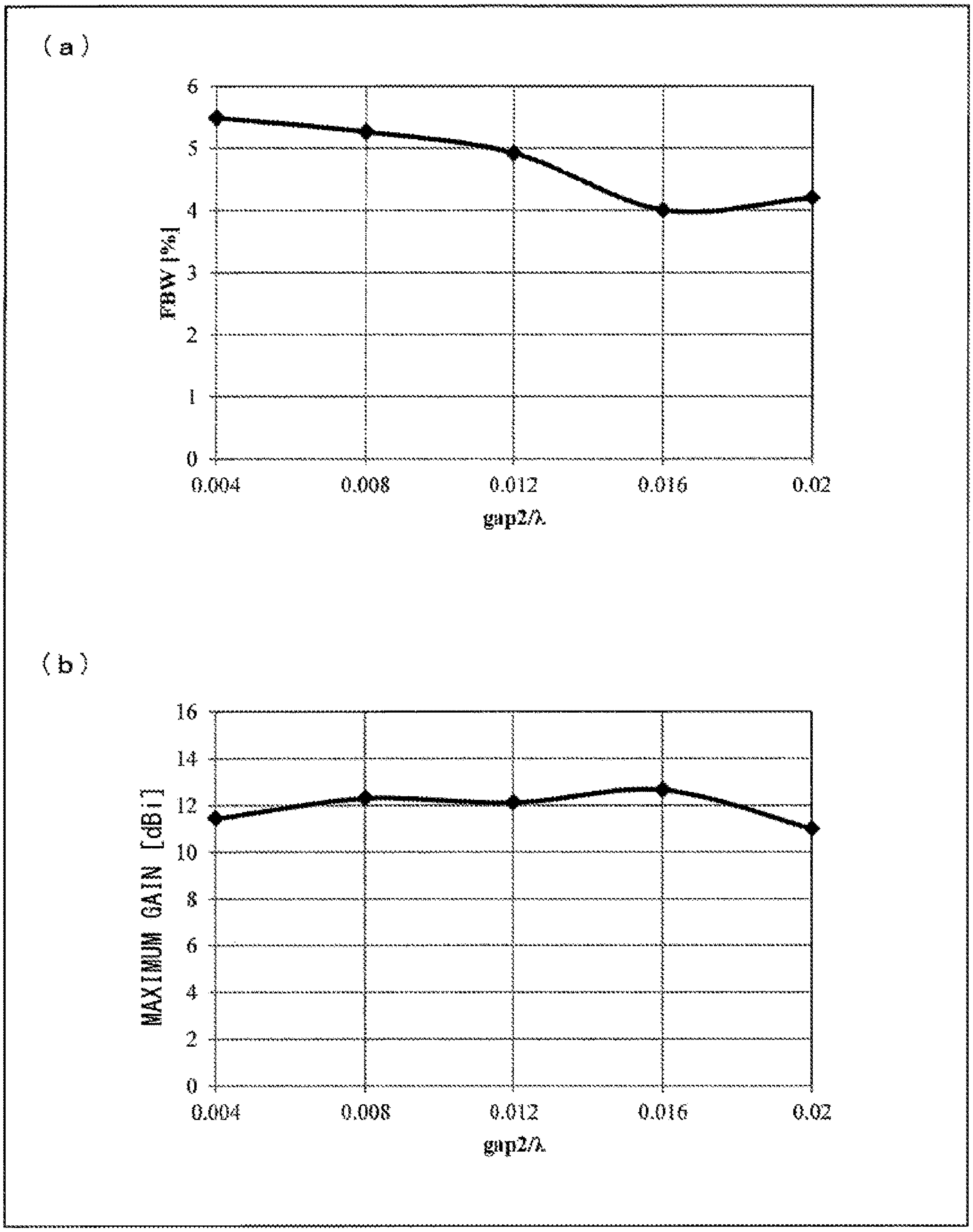

(a)
FBW [%]
6
5
4
3
2
1
0
0.004
0.008
0.012
0.016
0.02
gap2/λ
(b)
MAXIMUM GAIN [dBi]
16
14
12
10
8
6
4
2
0
0.004
0.008
0.012
0.016
0.02
gap2/λ

FIG. 22

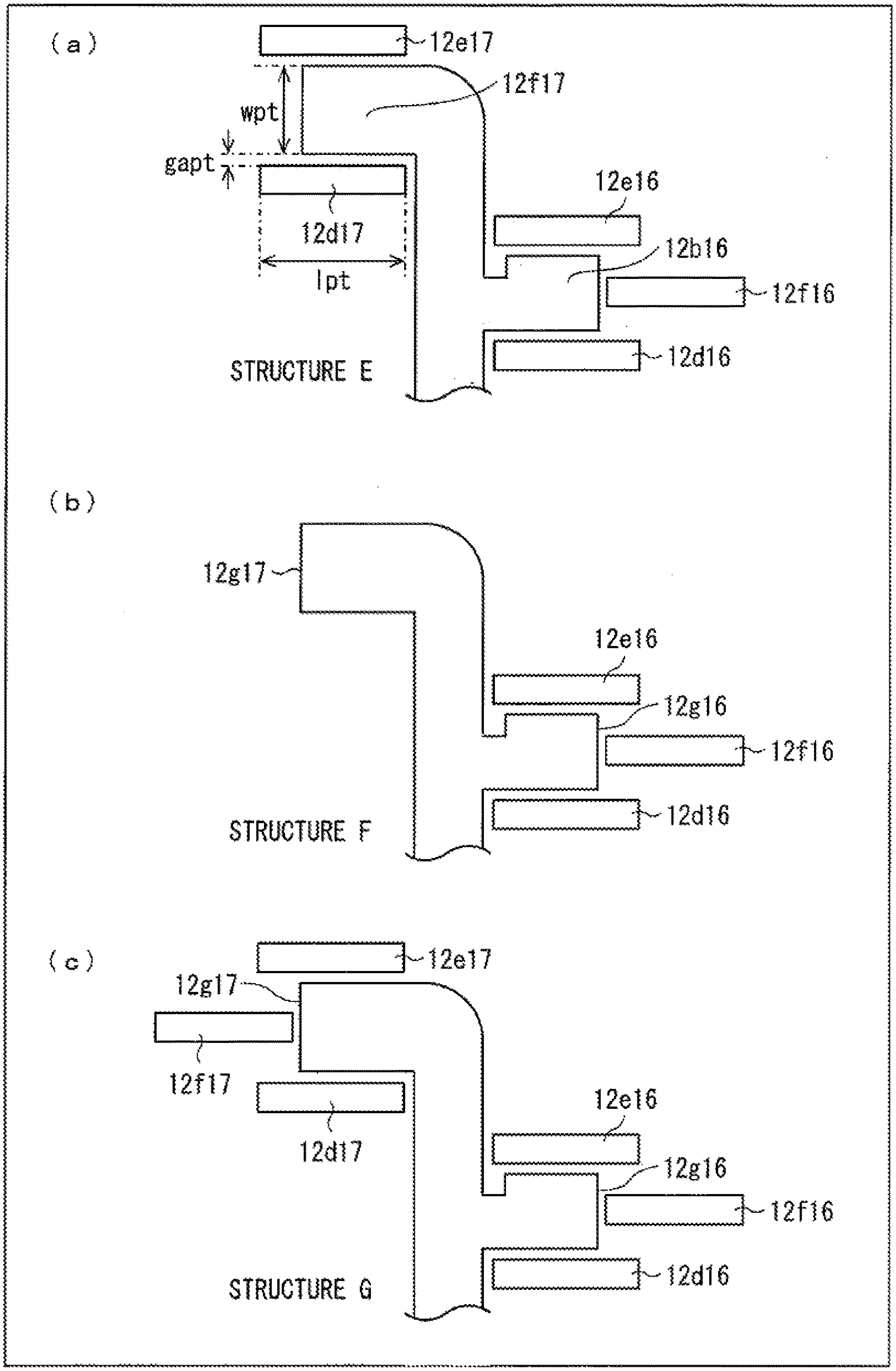

(a)
12e17
12f17
wpt
gapt
12d17
lpt
12e16
12b16
12f16
12d16
STRUCTURE E
(b)
12g17
12e16
12g16
12f16
12d16
STRUCTURE F
(c)
12e17
12g17
12f17
12d17
12e16
12g16
12f16
12d16
STRUCTURE G

FIG. 23

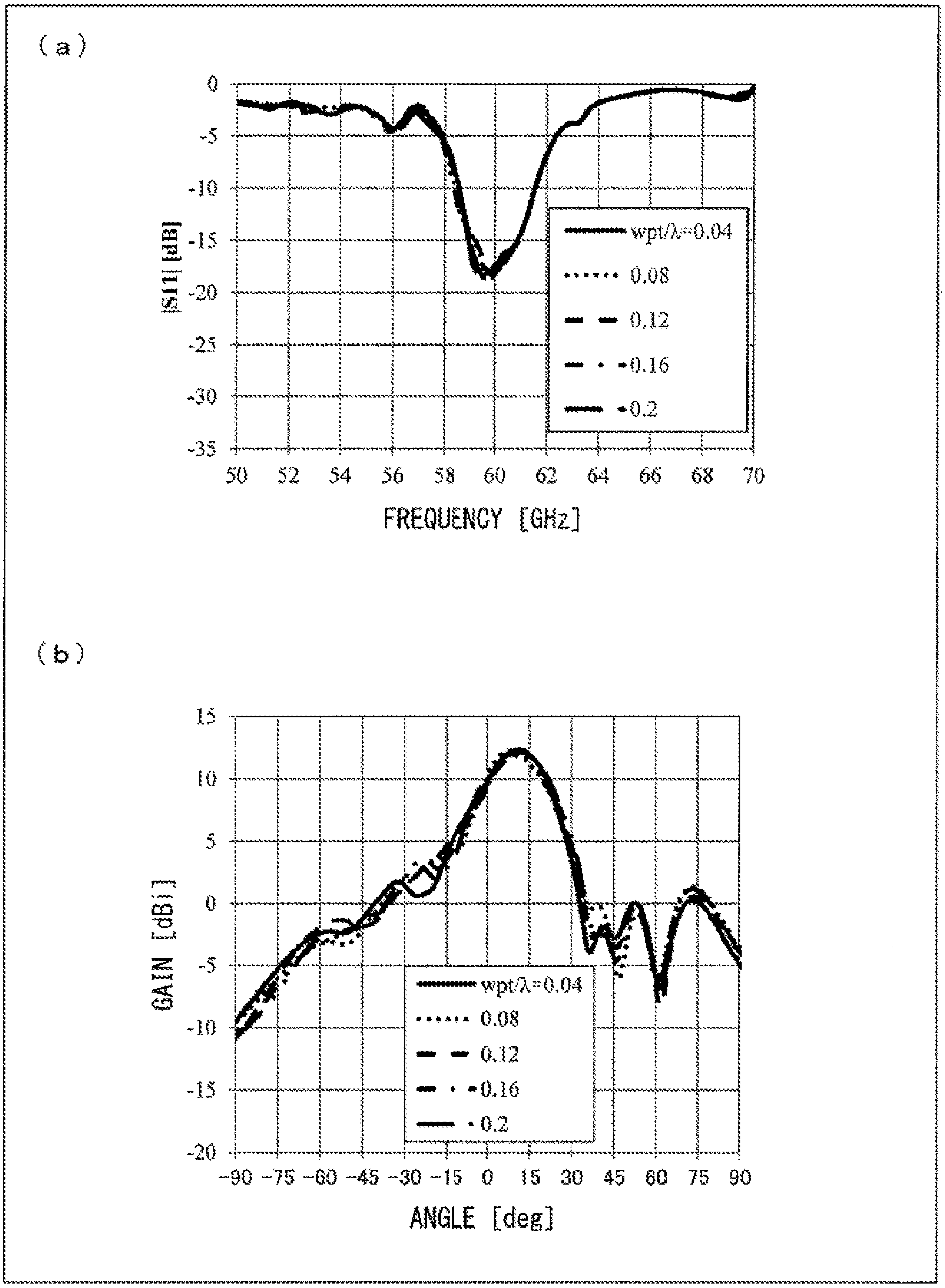

(a)
|S11| [dB]
0
-5
-10
-15
-20
-25
-30
-35
50 52 54 56 58 60 62 64 66 68 70
FREQUENCY [GHz]
wpt/λ=0.04
0.08
0.12
0.16
0.2
(b)
GAIN [dBi]
15
10
5
0
-5
-10
-15
-20
−90 −75 −60 −45 −30 −15 0 15 30 45 60 75 90
ANGLE [deg]
wpt/λ=0.04
0.08
0.12
0.16
0.2

FIG. 24

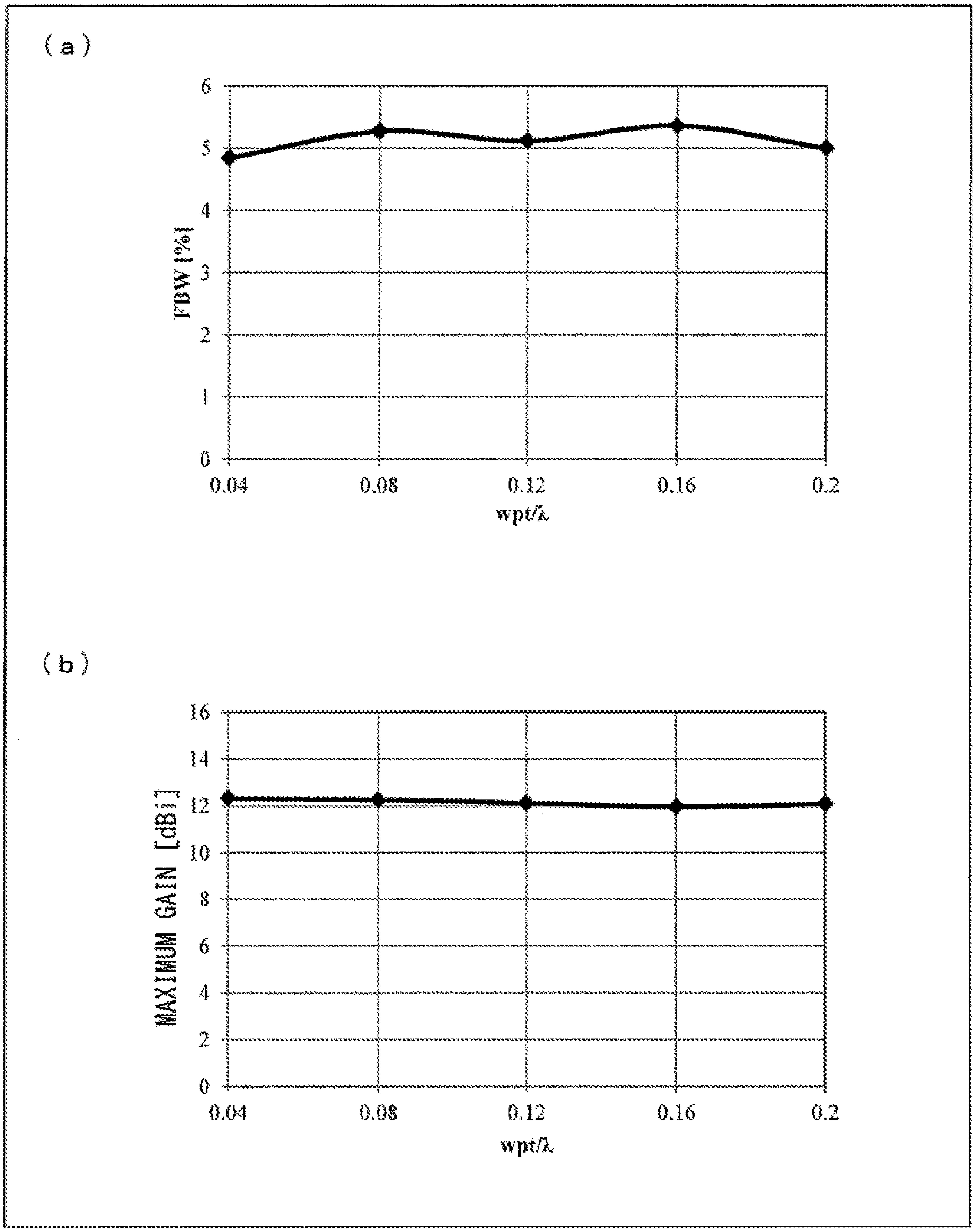
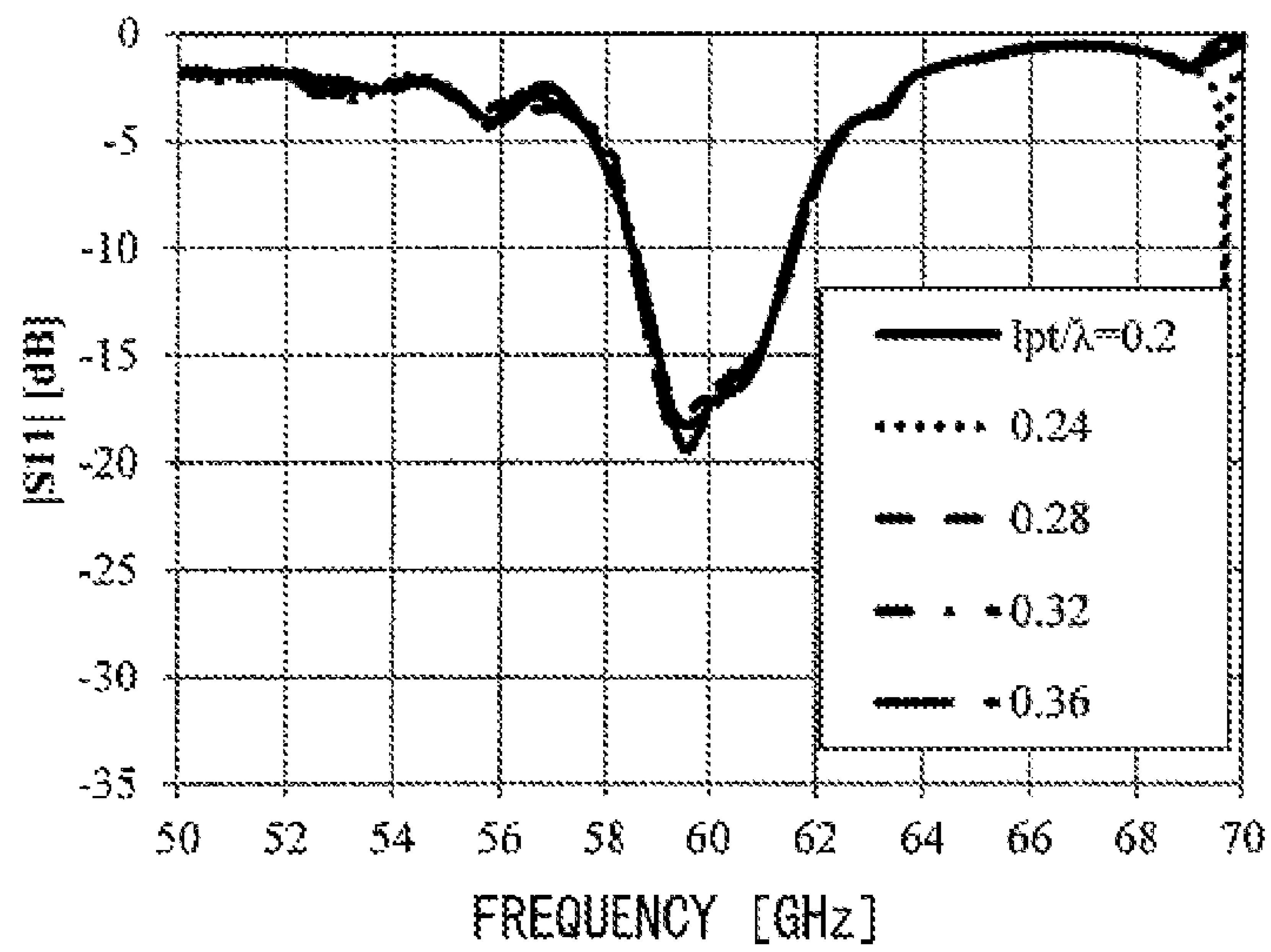

(a)
6
5
4
3
2
1
0
FBW [%]
0.04
0.08
0.12
0.16
0.2
wpt/λ
(b)
16
14
12
10
8
6
4
2
0
MAXIMUM GAIN [dBi]
0.04
0.08
0.12
0.16
0.2
wpt/λ

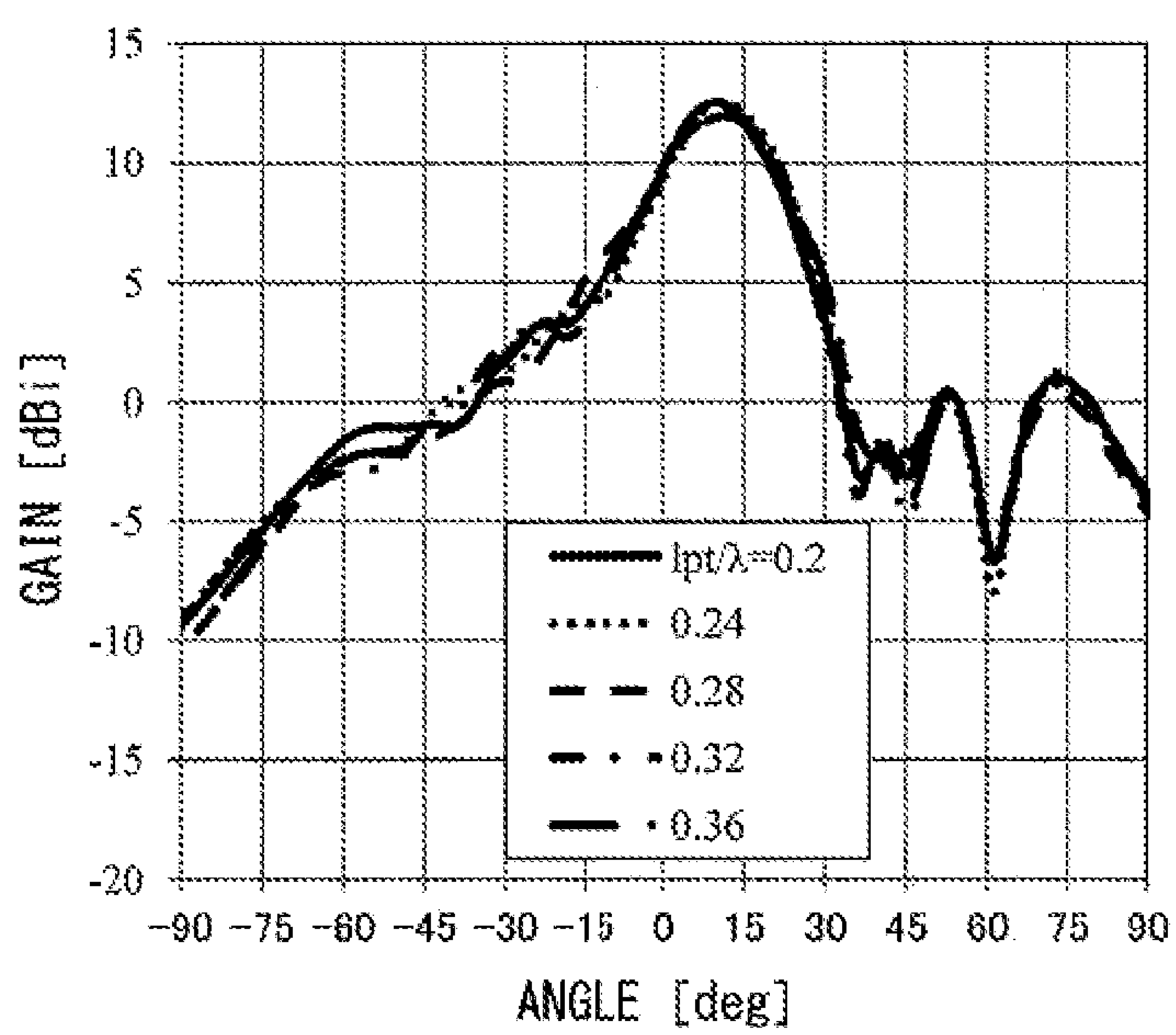
FIG. 25

(a)



0
-5
-10
-15
-20
-25
-30
-35
|S11| [dB]
50
52
54
56
58
60
62
64
66
68
70
FREQUENCY [GHz]
lpt/λ=0.2
0.24
0.28
0.32
0.36

(b)



15
10
5
0
-5
-10
-15
-20
GAIN [dBi]
−90 −75 −60 −45 −30 −15 0 15 30 45 60 75 90
ANGLE [deg]
lpt/λ=0.2
0.24
0.28
0.32
0.36

FIG. 26

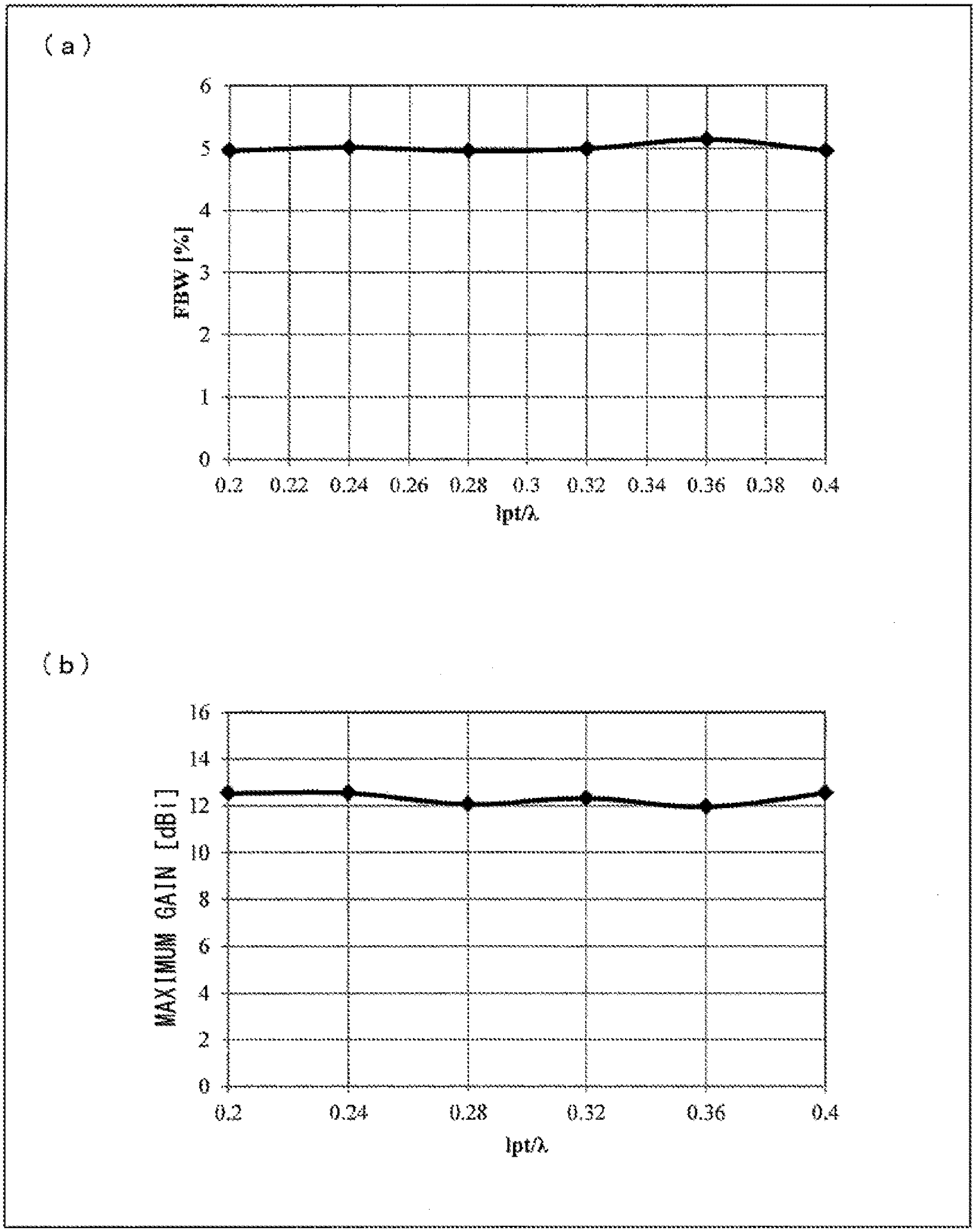
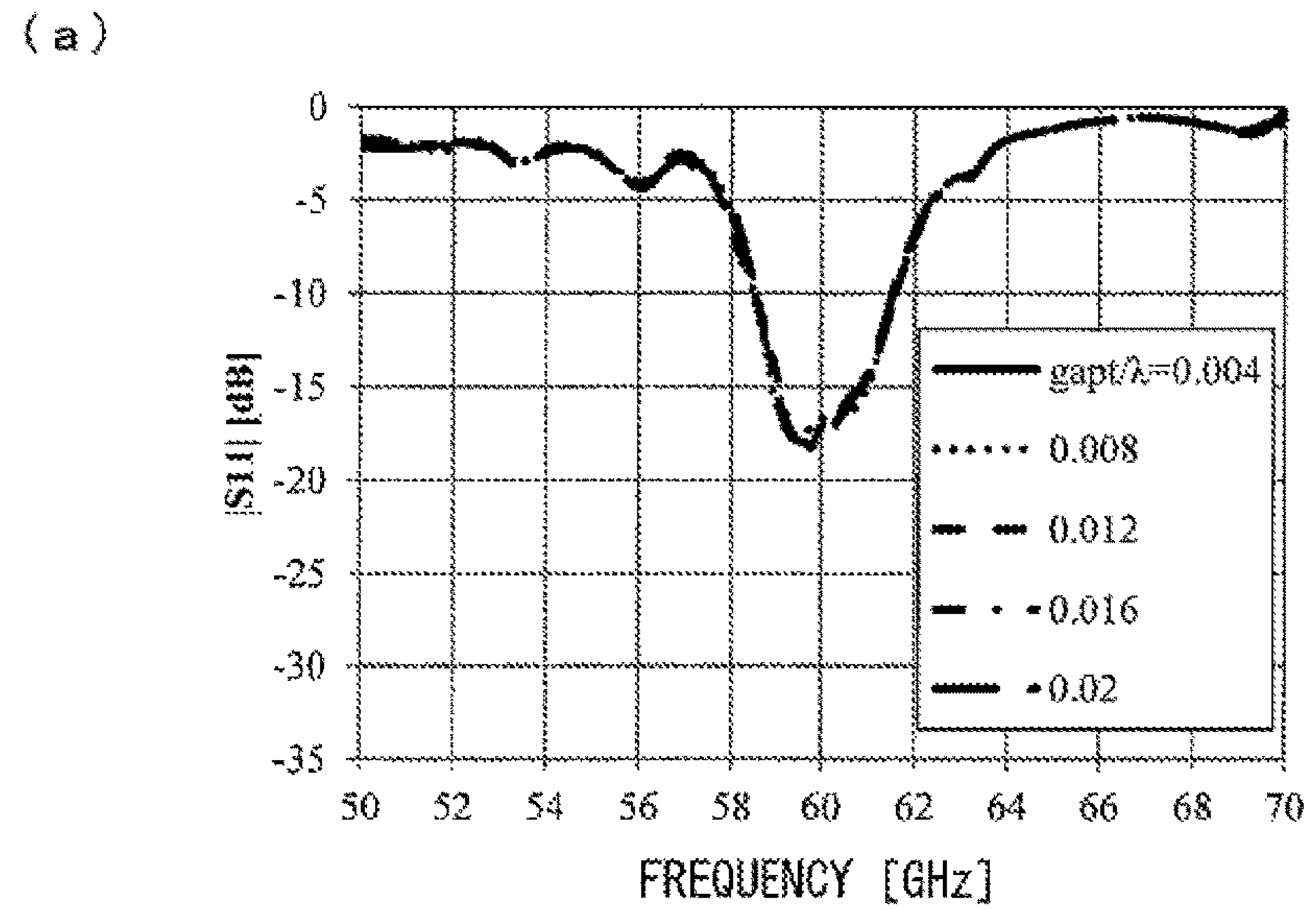

(a)
6
5
4
3
2
1
0
FBW [%]
0.2 0.22 0.24 0.26 0.28 0.3 0.32 0.34 0.36 0.38 0.4
lpt/λ
(b)
16
14
12
10
8
6
4
2
0
MAXIMUM GAIN [dBi]
0.2 0.24 0.28 0.32 0.36 0.4
lpt/λ

FIG. 27


(a)
0
-5
-10
-15
-20
-25
-30
-35
|S11| [dB]
50 52 54 56 58 60 62 64 66 68 70
FREQUENCY [GHz]
gapt/λ=0.004
0.008
0.012
0.016
0.02

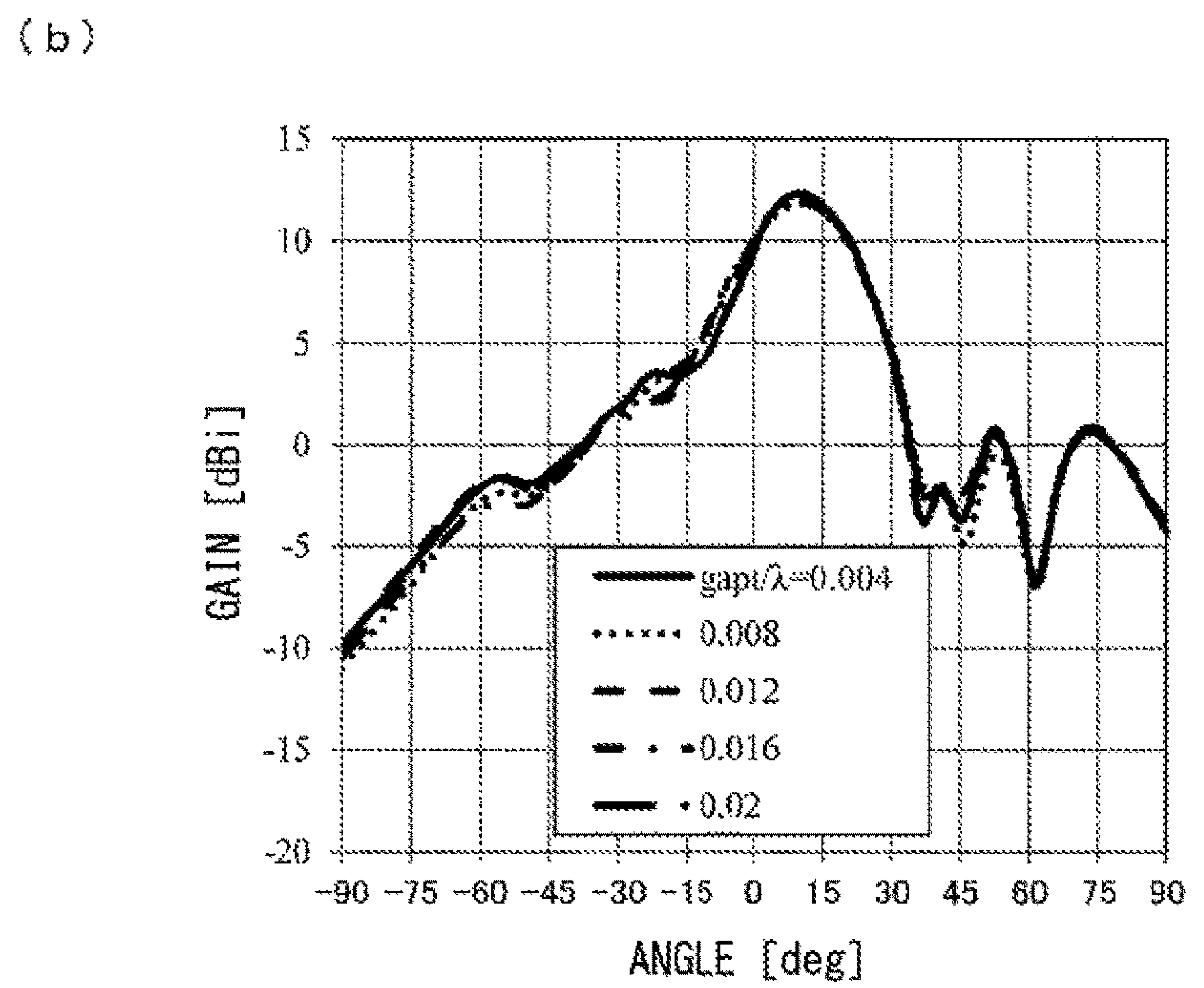

(b)
15
10
5
0
-5
-10
-15
-20
GAIN [dBi]
−90 −75 −60 −45 −30 −15 0 15 30 45 60 75 90
ANGLE [deg]
gapt/λ=0.004
0.008
0.012
0.016
0.02

FIG. 28

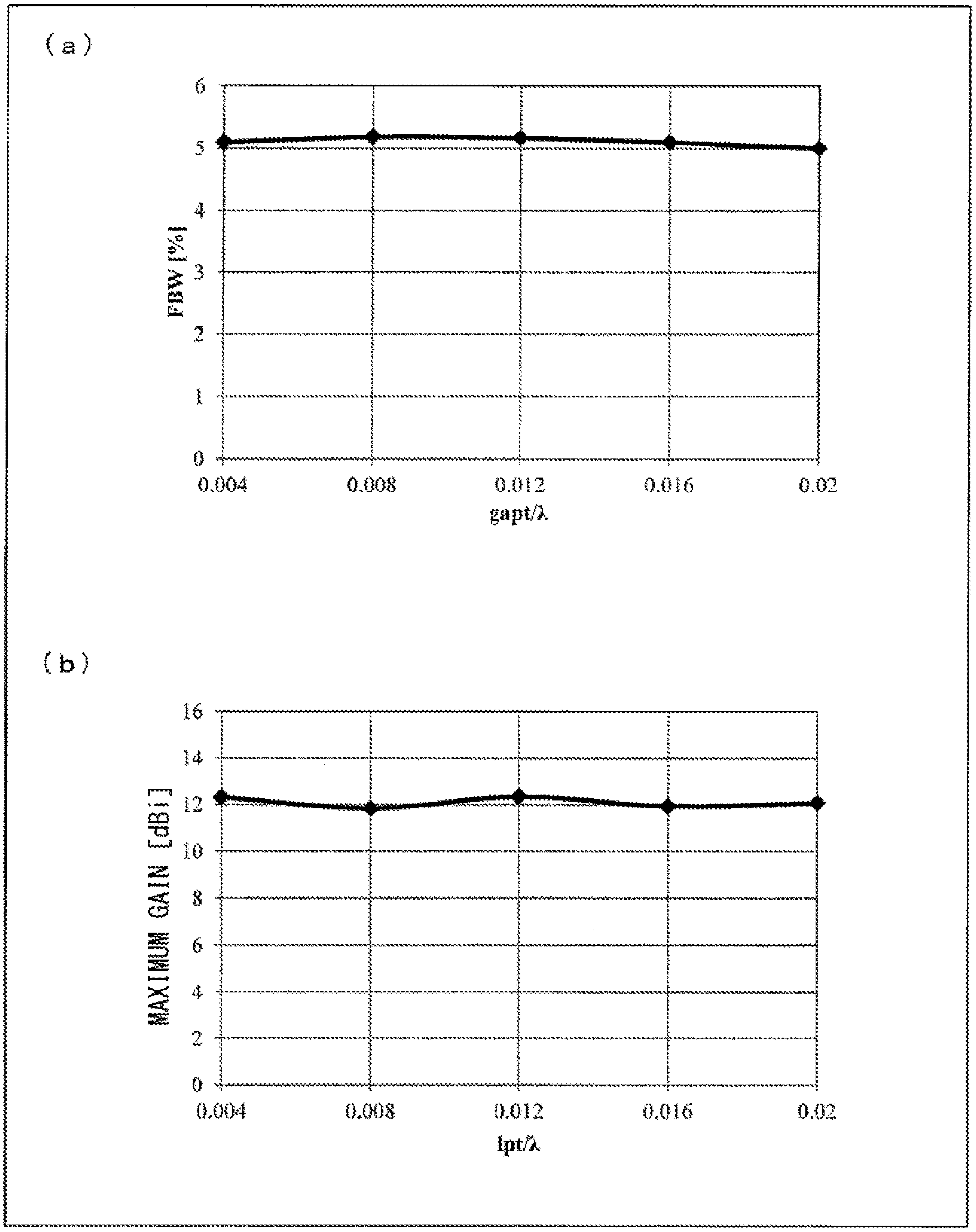
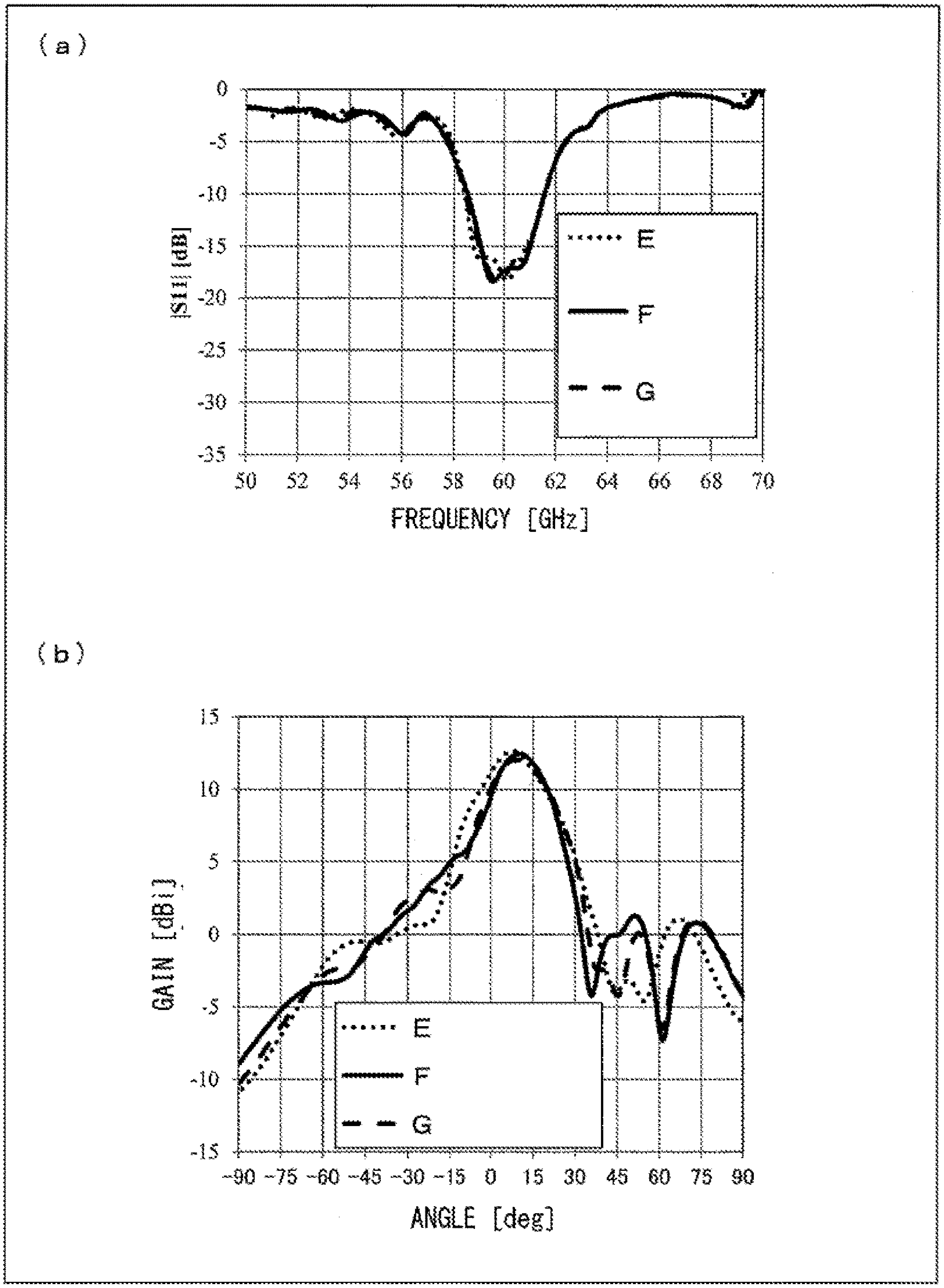

(a)
FBW [%]
6
5
4
3
2
1
0
0.004
0.008
0.012
0.016
0.02
gapt/λ
(b)
MAXIMUM GAIN [dBi]
16
14
12
10
8
6
4
2
0
0.004
0.008
0.012
0.016
0.02
lpt/λ

FIG. 29


(a)
0
-5
-10
-15
-20
-25
-30
-35
|S11| [dB]
50 52 54 56 58 60 62 64 66 68 70
FREQUENCY [GHz]
E
F
G
(b)
15
10
5
0
-5
-10
-15
GAIN [dBi]
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE [deg]
E
F
G

MICROSTRIP ANTENNA

TECHNICAL FIELD

The present invention relates to a microstrip antenna including a comb-line antenna conductor.

BACKGROUND ART

In line with advancement of wireless communications in terms of increased speed and capacity and advancement of wireless devices in terms of reduced size, there is an increasing demand for an antenna that operates in a millimeter wave band (not lower than 30 GHz and not higher than 300 GHz). Since a higher frequency causes a greater conductor loss and a greater dielectric loss, it is important that an antenna that operates in a millimeter wave band be designed so that a conductor loss and a dielectric loss are reduced.

As a transmission line for transmitting an electromagnetic wave in a millimeter wave band, a waveguide is suitably used. As an antenna for radiating an electromagnetic wave in a millimeter wave band, a comb-line microstrip antenna is suitably used.

Patent Literature 1 discloses a comb-line microstrip antenna. Patent Literature 2 discloses an antenna in which a waveguide is attached to a comb-line microstrip antenna.

CITATION LIST

Patent Literatures

[Patent Literature 1]
Japanese Patent Application Publication, Tokukai, No. 2009-188683 (publication date: Aug. 20, 2009)
[Patent Literature 2]
Japanese Patent Application Publication, Tokukai, No. 2011-223050 (publication date: Nov. 4, 2011)

SUMMARY OF INVENTION

Technical Problem

An antenna is generally required to exhibit an excellent reflection characteristic and an excellent radiation characteristic. An antenna is required to exhibit a reflection characteristic of, for example, having a reflection coefficient which is not more than −10 dB in an operation band. Further, an antenna is required to exhibit a radiation characteristic of, for example, having (i) a maximum gain which is not less than 10 dBi and (ii) a side lobe level which is not less than 10 dB.

The antennas disclosed in Patent Literatures 1 and 2 still have room for improvement in structure for the purpose of obtaining an excellent reflection characteristic and an excellent radiation characteristic.

Inventors of the present invention made an invention of a structure of an antenna that makes it possible to obtain an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic, and an applicant of the present application filed this invention (Japanese Patent Application No.: Tokugan, No. 2013-170662 (filing date: Aug. 20, 2013)) prior to filing of the present application. The antenna in accordance with the invention of the prior application exhibits an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic in a specific band. Note, however, that the antenna in accordance

with the invention of the prior application still have room for improvement in structure for the purpose of expanding a width of a band in which an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic are exhibited.

An object of the present invention is to allow a microstrip antenna including a comb-line antenna conductor to expand a width of a band in which an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic are exhibited.

Solution to Problem

In order to attain the object, a microstrip antenna in accordance with the present invention includes: a dielectric substrate; a comb-line antenna conductor provided on a front surface of the dielectric substrate and including: a power feeding line that extends in a first direction; and a stub that extends from the power feeding line in a second direction orthogonal to the first direction; a ground conductor provided on a back surface of the dielectric substrate; a first parasitic element provided on the front surface of the dielectric substrate and facing a first side of the stub which first side is on a side of a direction opposite to the first direction; and a second parasitic element provided on the front surface of the dielectric substrate and facing a second side of the stub which second side is on the first direction side.

According to the arrangement, functions of the first parasitic element and the second parasitic element make it possible to expand a width of a band in which an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic are exhibited.

Advantageous Effects of Invention

The present invention makes it possible to provide an antenna that allows expansion of a width of a band in which an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic are exhibited.

BRIEF DESCRIPTION OF DRAWINGS

(a) of FIG. **1** is a plan view of an antenna in accordance with an embodiment. (b) of FIG. **1** is a side view of the antenna. (c) of FIG. **1** is a bottom view of the antenna. (d) of FIG. **1** is an elevation view of the antenna.

FIG. **2** is a cross sectional view, taken from line AA', of the antenna in accordance with the embodiment.

FIG. **3** is a plan view of an antenna in accordance with an Example, the plan view showing sizes of sections of the antenna.

FIG. **4** is a bottom view of the antenna in accordance with the Example, the bottom view showing sizes of sections of the antenna.

(a) of FIG. **5** is a graph showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. **5** is graphs each showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. **6** is a plan view of the antenna in accordance with the Example. (b) and (c) of FIG. **6** are plan views of antennas in accordance with Comparative Examples. (d) of FIG. **6** is a plan view of an antenna in accordance with another Example. The antennas illustrated in (b) through (d) of FIG. **6** are each obtained by omitting a part or all of a parasitic element included in an antenna element of the antenna illustrated in (a) of FIG. **6**.

FIG. 7 is graphs showing respective reflection characteristics of the antennas illustrated in (a) through (d) of FIG. 6.

FIG. 8 is a plan view of the antenna in accordance with the Example and shows definitions of (i) a width wp1 of a first parasitic element included in an antenna element, (ii) a length lp1 of the first parasitic element, and (iii) a gap gap1 between the first parasitic element and a first stub.

FIG. 9 is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized width wp1/λ is set at 0.04, 0.08, 0.12, 0.16, and 0.2. (a) of FIG. 9 is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. 9 is graphs each showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. 10 is a graph showing a 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the normalized width wp1/λ is set at 0.04, 0.08, 0.12, 0.16, and 0.2. (b) of FIG. 10 is a graph showing a maximum gain of the antenna in accordance with the Example and obtained in a case where the normalized width wp1/λ is set at 0.04, 0.08, 0.12, 0.16, and 0.2.

FIG. 11 is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized length lp1/λ is set at 0.08, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36, and 0.40. (a) of FIG. 11 is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. 11 is graphs each showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. 12 is a graph showing the 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the normalized length lp1/λ is set at 0.08, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36, and 0.40. (b) of FIG. 12 is a graph showing the maximum gain of the antenna in accordance with the Example and obtained in a case where the normalized length lp1/λ is set at 0.08, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36, and 0.40.

FIG. 13 is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized gap between the first parasitic element and the first stub gap1/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02. (a) of FIG. 13 is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. 13 is graphs each showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. 14 is a graph showing the 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the normalized gap between the first parasitic element and the first stub gap1/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02. (b) of FIG. 14 is a graph showing the maximum gain of the antenna in accordance with the Example and obtained in a case where the normalized gap between the first parasitic element and the first stub gap1/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02.

FIG. 15 is a plan view of the antenna in accordance with the Example and shows definitions of (i) a width wp2 of a third parasitic element included in an antenna element, (ii) a length lp2 of the third parasitic element, and (iii) a gap gap2 between the third parasitic element and the first stub.

FIG. 16 is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized width wp2/λ is set at 0.02, 0.04, 0.06, 0.08, and 0.1. (a) of FIG. 16 is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. 16 is a view showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. 17 is a graph showing the 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the normalized width wp2/λ is set at 0.02, 0.04, 0.06, 0.08, and 0.1. (b) of FIG. 17 is a graph showing the maximum gain of the antenna in accordance with the Example and obtained in a case where the normalized width wp2/λ is set at 0.02, 0.04, 0.06, 0.08, and 0.1.

FIG. 18 is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized length lp2/λ is set at 0.08, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36, and 0.40. (a) of FIG. 18 is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. 18 is graphs each showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. 19 is a graph showing the 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the normalized length lp2/λ is set at 0.08, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36, and 0.40. (b) of FIG. 19 is a graph showing the maximum gain of the antenna in accordance with the Example and obtained in a case where the normalized length lp2/λ is set at 0.08, 0.12, 0.16, 0.20, 0.24, 0.28, 0.32, 0.36, and 0.40.

FIG. 20 is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized gap between the third parasitic element and the first stub gap2/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02. (a) of FIG. 20 is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. 20 is graphs each showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. 21 is a graph showing the 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the normalized gap between the third parasitic element and the first stub gap2/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02. (b) of FIG. 21 is a graph showing the maximum gain of the antenna in accordance with the Example and obtained in a case where the normalized gap between the third parasitic element and the first stub gap2/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02.

(a) of FIG. 22 is a plan view of the antenna in accordance with the Example and shows definitions of (i) a length lpt of a fourth parasitic element provided at a terminal end of a microstrip line, (ii) a width wpt of a second stub, and (iii) a gap gapt between the fourth parasitic element and the second stub. (b) and (c) of FIG. 22 are plan views of antennas in accordance with the Comparative Examples. The antennas in accordance with the Comparative Examples are each obtained by omitting, in the antenna in accordance with the Example, a parasitic element included in an antenna element, or by adding a new parasitic element in the antenna in accordance with the Example.

FIG. 23 is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized width wpt/λ is set at 0.04, 0.08, 0.12, 0.16, and 0.2. (a) of FIG. 23 is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. 23 is a view showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. 24 is a graph showing the 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the normalized width wpt/λ is set at 0.04, 0.08, 0.12, 0.16, and 0.2. (b) of FIG. **24** is a graph showing the maximum gain of the antenna in accordance with the Example and obtained in a case where the normalized width wpt/λ is set at 0.04, 0.08, 0.12, 0.16, and 0.2.

FIG. **25** is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized length lpt/λ is set at 0.2, 0.24, 0.28, 0.32, and 0.36. (a) of FIG. **25** is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. **25** is graphs each showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. **26** is a graph showing the 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the normalized length lpt/λ is set at 0.2, 0.24, 0.28, 0.32, and 0.36. (b) of FIG. **26** is a graph showing the maximum gain of the antenna in accordance with the Example and obtained in a case where the normalized length lpt/λ is set at 0.2, 0.24, 0.28, 0.32, and 0.36.

FIG. **27** is graphs showing characteristics of the antenna in accordance with the Example and obtained in a case where a normalized gap between the fourth parasitic element and the second stub gapt/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02. (a) of FIG. **27** is graphs each showing a reflection characteristic of the antenna in accordance with the Example. (b) of FIG. **27** is graphs each showing a radiation characteristic of the antenna in accordance with the Example.

(a) of FIG. **28** is a graph showing the 10 dB fractional band width of the antenna in accordance with the Example and obtained in a case where the gap between the fourth parasitic element and the second stub gapt/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02. (b) of FIG. **28** is a graph showing the maximum gain of the antenna in accordance with the Example and obtained in a case where the gap between the fourth parasitic element and the second stub gapt/λ is set at 0.004, 0.008, 0.012, 0.016, and 0.02.

FIG. **29** is graphs showing characteristics of the antennas illustrated in (a) through (c) of FIG. **22**. (a) of FIG. **29** is graphs showing respective reflection characteristics of the antennas illustrated in (a) through (c) of FIG. **22**. (b) of FIG. **29** is graphs showing respective radiation characteristics of the antennas illustrated in (a) through (c) of FIG. **22**.

DESCRIPTION OF EMBODIMENTS

[Arrangement of Antenna]

An arrangement of an antenna **1** in accordance with an embodiment of the present invention is described below with reference to FIG. **1**. (a) of FIG. **1** is a plan view of the antenna **1**. (b) of FIG. **1** is a side view of the antenna **1**. (c) of FIG. **1** is a bottom view of the antenna **1**. (d) of FIG. **1** is an elevation view of the antenna **1**.

The antenna **1** includes a dielectric substrate **11**, an antenna conductor **12**, a ground conductor **13**, a waveguide **14**, a shield **15**, and short-circuit parts **16**. The antenna **1** is obtained by attaching the waveguide **14**, the shield **15**, and the short-circuit parts **16** to a microstrip antenna constituted by the dielectric substrate **11**, the antenna conductor **12**, and the ground conductor **13**.

The dielectric substrate **11** is a plate member having a rectangular main surface, and is made of a dielectric substance such as resin. According to the present embodiment, a liquid crystal polymer (LCP) substrate made of a liquid crystal polymer is used as the dielectric substrate **11**.

In the present specification, of six surfaces constituting an entire surface of the dielectric substrate **11**, two surfaces having the largest area are each referred to as a "main surface", and the other four surfaces are each referred to as an "end surface". In a case where it is necessary to distinguish between the two main surfaces of the dielectric substrate **11**, one and the other of the two main surfaces are referred to as a "front surface" and a "back surface", respectively. Further, the present specification uses a coordinate system in which an x-axis is an axis parallel to a short side of a main surface of the dielectric substrate **11**, a y-axis is an axis parallel to a long side of the main surface of the dielectric substrate **11**, and a z-axis is an axis orthogonal to the main surface of the dielectric substrate **11**.

The antenna conductor **12** is a foil member provided on a front surface of the dielectric substrate **11**, and is made of a conductor such as metal. According to the present embodiment, copper foil provided on the front surface of the dielectric substrate **11** is used as the antenna conductor **12**.

The antenna conductor **12** is a comb-line antenna conductor in which a plurality of stubs **12*b*1** through **12*b*16** and a stub **12*g*17** are attached to a power feeding line **12*a***, which extends in a direction (first direction) parallel to the y-axis. In a vicinity of each stub **12*bi*** that extends in an x-axis direction from an intermediate part of the power feeding line **12*a***, there are provided a first parasitic element **12*di***, a second parasitic element **12*ei***, and a third parasitic element **12*fi*** (i=1, 2, . . . , 16). In a vicinity of the stub **12*g*17**, which extends from a tip of the power feeding line **12*a***, there are provided a fourth parasitic element **12*d*17** and a fifth parasitic element **12*e*17**.

In the following description, the plurality of stubs **12*b*1** through **12*b*16** is collectively written as a "stub **12*b***" in a case where it is unnecessary to specify any one of the plurality of stubs **12*bl*** through **12*b*16**. Similarly, first parasitic elements **12*dl*** through **12*d*16** are collectively written as a "first parasitic element **12*d***", second parasitic elements **12*e*1** through **12*e*16** are collectively written as a "second parasitic element **12*e***", and third parasitic elements **12*f*1** through **12*f*16** are collectively written as a "third parasitic element **12*f***".

The power feeding line **12*a*** is a belt-shaped conductor serving as a trunk of the antenna conductor **12**, and extends in parallel to the y-axis. Together with the ground conductor **13**, which faces the power feeding line **12*a*** via the dielectric substrate **11**, the power feeding line **12*a*** constitutes a microstrip line. An electromagnetic wave that has entered an input end (an end on the y-axis negative direction side) of the power feeding line **12*a*** propagates through the microstrip line toward a terminal end (an end on the y-axis positive direction side) of the power feeding line **12*a***.

The stub **12*b*** and the stub **12*g*17** are belt-shaped conductors serving as branches of the antenna conductor **12**, and extend in a direction (second direction) parallel to the x-axis. Note here that the stub **12*b*** is a stub whose starting point is the intermediate part (a part between the input end and the terminal end) of the power feeding line **12*a*** and the stub **12*g*17** is a stub whose starting point is the terminal end of the power feeding line **12*a***. The stubs **12*b*1** through **12*b*16** include (i) first stubs extending from the power feeding line **12*a*** in an x-axis negative direction (stubs each having a reference sign whose final number is an odd number) and (ii) second stubs extending from the power feeding line **12*a*** in an x-axis positive direction (stubs each having a reference sign whose final number is an even number). The first stubs and the second stubs are alternately provided along the power feeding line **12*a***. The stub **12*b*** has a root provided with a slit **12***c* that extends from the terminal end side of the power feeding line **12***a* toward the input end side of the power feeding line **12***a*. The stub **12***g***17**, which is provided at the terminal end of the power feeding line **12***a*, extends in the x-axis negative direction.

The first parasitic element **12***d* is provided so as to face a side (first side) of the stub **12***b* which side is on the y-axis negative direction (direction opposite to the first direction) side. The second parasitic element **12***e* is provided so as to face a side (second side) of the stub **12***b* which side is on the y-axis positive direction (first direction) side. The third parasitic element **12***f* is provided so as to face a side (third side) of the stub **12***b* which side is on the x-axis direction side. The side on the x-axis direction side can be reworded as a side of the stub **12***b* which side is located at a terminal of the stub **12***b*.

The first parasitic element **12***d*, the second parasitic element **12***e*, and the third parasitic element **12***f* each preferably have a rectangular shape in which the x-axis direction is a longer side direction. Further, the shape of the first parasitic element **12***d* and the shape of the second parasitic element **12***e* are preferably congruent with each other.

The fourth parasitic element **12***d***17** is provided so as to face a side of the stub **12***g***17** provided at the terminal end of the power feeding line **12***a*, the side being on a side of a direction opposite to the y-axis direction. The fifth parasitic element **12***e***17** is provided so as to face a side of the stub **12***g***17** which side is on the y-axis direction side.

The fourth parasitic element **12***d***17** and the fifth parasitic element **12***e***17** each preferably have a rectangular shape in which the x-axis direction is a longer side direction. Further, the shape of the fourth parasitic element **12***d***17** and the shape of the fifth parasitic element **12***e***17** are preferably congruent with each other.

An electromagnetic wave that has propagated through the microstrip line constituted by the power feeding line **12***a* and the ground conductor **13** is radiated from the stub **12***b* to an outside. In this case, an electric current is induced also to the first parasitic element **12***d* that has been spatially coupled with the stub **12***b*, so that the electromagnetic wave is radiated also from the first parasitic element **12***d*. Similarly, the electromagnetic wave is radiated also from each of the second parasitic element **12***e* and the third parasitic element **12***f*. Specifically, the stub **12***b*, the first parasitic element **12***d*, the second parasitic element **12***e*, and the third parasitic element **12***f* function as a single antenna element, and the stub **12***g***17**, the fourth parasitic element **12***d***17**, and the fifth parasitic element **12***e***17** function as a single antenna element.

The first parasitic element **12***d*, the second parasitic element **12***e*, and the third parasitic element **12***f* are designed to have a resonance frequency that is close to a resonance frequency of the stub **12***b*. Similarly, the fourth parasitic element **12***d***17** and the fifth parasitic element **12***e***17** are designed to have a resonance frequency that is close to a resonance frequency of the stub **12***g***17**. The first parasitic element **12***d*, the second parasitic element **12***e*, the third parasitic element **12***f*, the fourth parasitic element **12***d***17**, and the fifth parasitic element **12***e***17** which are thus designed allow an operation band of the antenna **1** to be broader.

The ground conductor **13** is a foil member provided on a back surface of the dielectric substrate **11**, and is made of a conductor such as metal. According to the present embodiment, copper foil provided on the back surface of the dielectric substrate **11** is used as the ground conductor **13**.

The ground conductor **13** has an opening **13***a*. The opening **13***a* has a rectangular shape whose long side is parallel to the x-axis. The opening **13***a* is provided in a region of the back surface of the dielectric substrate **11** in which region the opening **13***a* overlaps the input end of the power feeding line **12***a*. The ground conductor **13** entirely covers the back surface of the dielectric substrate **11** except for this region.

The waveguide **14** is a tubular member whose both ends are open, and is made of a conductor such as metal. The waveguide **14** has therein a cavity **14***b* that has a rectangular transverse section (cross section orthogonal to a tube axis). The waveguide **14** is provided so that the tube axis is parallel to the z-axis and a longer side axis of the transverse section of the cavity **14***b* is parallel to the x-axis. Further, the waveguide **14** has a tube wall **14***a* whose z-axis positive direction side end surface is joined to the ground conductor **13**. An image of the cavity **14***b* orthogonally projected onto an x-y plane includes an image of the opening **13***a* orthogonally projected onto the x-y plane.

The shield **15** is a foil member provided on the front surface of the dielectric substrate **11**, and is made of a conductor such as metal. According to the present embodiment, copper foil provided on the front surface of the dielectric substrate **11** is used as the shield **15**.

The shield **15** has a rectangular shape whose long sides are parallel to the x-axis and which is provided with a slit **15***a* that extends from the y-axis positive direction side long side toward the y-axis negative direction side long side. The shield **15** is provided so that the input end of the power feeding line **12***a* enters the slit **15***a*. Assuming that the slit **15***a* is absent, an image of the shield **15** orthogonally projected onto the x-y plane includes the image of the cavity **14***b* orthogonally projected onto the x-y plane.

The shield **15** is short-circuited with the ground conductor **13** via the short-circuit parts **16**, which are through the dielectric substrate **11**. The short-circuit parts **16** are provided, around an entire outer circumference of the shield **15** except for a place where the slit **15***a* is provided, so as to constitute a fence surrounding a region inside the dielectric substrate **11** which region overlaps the opening **13***a*.

The antenna **1** is supplied with an electromagnetic wave via the waveguide **14**. A TE**01** mode electromagnetic wave that propagates through the waveguide **14** in a z-axis positive direction enters the dielectric substrate **11** via the opening **13***a* of the ground conductor **13**. The region inside the dielectric substrate **11** which region overlaps the opening **13***a* has sides that are surrounded by the short-circuit parts **16** and an upper part that is covered with the shield **15**. Consequently, the electromagnetic wave that has entered the dielectric substrate **11** via the opening of the ground conductor **13** enters the input end of the power feeding line **12***a* without being dispersed around.

The antenna **1** is characteristic in that the slit **15***a* provided in the shield **15** has a reverse taper shape that has a greater width in an inner part of the slit **15***a*. The slit **15***a* which has a reverse taper shape allows an improvement in reflection characteristic and radiation characteristic of the antenna **1**.

According to the present embodiment, the slit **15***a* has an exponential taper shape whose Napier's number is e and in which a position in a longer side direction is a variable. Note, however, that the shape of the slit **15** is not limited to such a shape. Specifically, the slit **15** can have a linear taper shape whose width is in proportion to a distance from an open end of the slit **15** or a parabolic taper shape whose width is in proportion to a square root of a distance from the open end.

The following description additionally discusses a structure of a short-circuit part **16** with reference to FIG. **2**. FIG. **2** is a cross sectional view, taken from line AA', of the antenna **1**.

The shield **15** is provided with an opening **15***b* (see FIG. **2**). The dielectric substrate **11** is provided with a through hole **11***a* that communicates with the opening **15***b* (see FIG. **2**).

The opening **15***b* and the through hole **11***a* are each filled with a conductor such as solder. The conductor with which the opening **15***b* and the through hole **11***a* are each filled is brought into contact with both the shield **15** and the ground conductor **13**, so that the shield **15** and the ground conductor **13** are short-circuited. The short-circuit part **16** is nothing but a conductor with which the opening **15***b* and the through hole **11***a* are each thus filled.

As described earlier, the antenna **1** of the present invention includes: the dielectric substrate **11**; the antenna conductor **12** including: the power feeding line **12***a* that extends in the first direction; and the stub **12***b*; the ground conductor **13**; the first parasitic element **12***d* facing a first side of the stub **12***b* which first side is on a side of a direction opposite to the first direction; and the second parasitic element **12***e* facing a second side of the stub **12***b* which second side is on the first direction side.

This makes it possible to provide an antenna that allows expansion of a width of a band in which an excellent reflection characteristic and an excellent radiation characteristic are exhibited.

EXAMPLES

Next, an example of the antenna **1** illustrated in FIG. **1** is described below with reference to FIGS. **3** through **6**.

The antenna **1** in accordance with the present Example is obtained by attaching the waveguide **14**, the shield **15**, and the short-circuit parts **16** to a microstrip antenna (constituted by the dielectric substrate **11**, the antenna conductor **12**, and the ground conductor **13**) that operates at 60 GHz. Specifically, the antenna **1** in accordance with the present Example is obtained by setting sections of the antenna **1** illustrated in FIG. **1** to have sizes as shown in FIGS. **3** and **4**. Note here that a microstrip antenna that operates at 60 GHz means a microstrip antenna that has a design center frequency of 60 GHz.

FIG. **3** is a plan view of the antenna **1** in accordance with the present Example, the plan view showing sizes (unit: mm) of sections of the antenna **1**. FIG. **4** is a bottom view of the antenna **1** in accordance with the present Example, the bottom view showing sizes (unit: mm) of sections of the antenna **1**. The antenna **1** in accordance with the present Example is arranged such that the dielectric substrate **11** has a thickness of 0.175 mm. Further, the antenna **1** in accordance with the present Example is arranged such that the dielectric substrate **11** has a specific inductive capacity of 3.0 and a dielectric dissipation factor of 0.0025.

(a) of FIG. **5** is a graph showing a reflection characteristic (frequency dependence of a reflection coefficient |**S11**|) of the antenna **1** in accordance with the present Example. (b) of FIG. **5** is graphs each showing a radiation characteristic (directional dependence of a gain on each of a y-z plane and a z-x plane) of the antenna **1** at 60 GHz.

It is confirmed from (a) of FIG. **5** that the reflection coefficient |**S11**| at 60 GHz has a value of approximately −18 dB, which falls below a design target value of −10 dB. It is also confirmed that a width of a band in which the reflection coefficient |**S11**| falls below −10 dB is approximately 3 GHz.

It is confirmed from (b) of FIG. **5** (1) that a maximum gain is 12.0 dBi, which exceeds a design target value of 10 dBi and (2) that a side lobe level is 11 dBi, which exceeds a design target value of 10 dBi.

[Influence of Omission of Parasitic Elements on Characteristics]

The following description discusses, with reference to FIGS. **6** and **7**, an influence of omission of a part or all of the parasitic elements (the first parasitic element **12***d*, the second parasitic element **12***e*, and the third parasitic element **12***f*) on a reflection characteristic and a radiation characteristic of the antenna **1** in accordance with the present Example.

(a) of FIG. **6** is a plan view of the antenna **1** in accordance with the present Example. (b) through (d) of FIG. **6** are plan views of antennas in accordance with Comparative Examples. The following description compares characteristics of a group of antennas listed below. Note that the following description of (a) through (d) of FIG. **6** is given by taking, as an example, the stub **12***b***2**, the first parasitic element **12***d***2**, the second parasitic element **12***e***2**, and the third parasitic element **12***f***2**, which are an antenna element that comes second from the input end of the power feeding line **12***a*. An antenna element that comes first from the input end and antenna elements that comes third to sixteenth from the input end are similar in arrangement of the antenna element that comes second from the input end. In each of the antennas illustrated in (a) through (d) of FIG. **6**, an antenna element provided at the terminal end of the power feeding line **12***a* includes the stub **12***g***17**, the fourth parasitic element **12***d***17**, and the fifth parasitic element **12***e***17** as illustrated in FIG. **3**.

An antenna A is the antenna **1** in accordance with the present Example (see (a) of FIG. **6**).

An antenna B is obtained by omitting the first parasitic element **12***d***2**, the second parasitic element **12***e***2**, and the third parasitic element **12***f***2** in the antenna **1** in accordance with the present Example (see (b) of FIG. **6**).

An antenna C is obtained by omitting the first parasitic element **12***d***2** and the second parasitic element **12***e***2** in the antenna **1** in accordance with the present Example (see (c) of FIG. **6**).

An antenna D is obtained by omitting the third parasitic element **12***f***2** in the antenna **1** in accordance with the present Example (see (d) of FIG. **6**).

FIG. **7** is graphs showing respective reflection characteristics of the antennas A through D. A comparison of the respective reflection characteristics of the antennas A through D in FIG. **7** reveals that only the antenna A (the antenna **1** in accordance with the present Example) and the antenna D each have, at 60 GHz, the reflection coefficient |**S11**| whose value falls below a design target value of −10 dB. Thus, in order to obtain an excellent reflection characteristic at 60 GHz, an antenna preferably includes the first parasitic element **12***dl* and the second parasitic element **12***e***1** as in the antenna **1** in accordance with the present Example and the antenna D in accordance with a modification.

Further, it is confirmed that a band in which the antenna A has the reflection coefficient |**S11**| which falls below −10 dB is broader than a band in which the antenna D has the reflection coefficient |**S11**| which falls below −10 dB. Thus, in order to allow the operation band of the antenna **1** to be broader, an antenna more preferably includes not only the first parasitic element **12***dl* and the second parasitic element **12***e***1** but also the third parasitic element **12***f***2** as in the antenna **1** in accordance with the present Example 1.

[Influence of Sizes of First Parasitic Element and Second Parasitic Element on Characteristics]

The following description discusses, with reference to FIGS. **8** through **14**, an influence of sizes of the first parasitic element **12***d* and the second parasitic element **12***e* on characteristics of the antenna **1** in accordance with the present Example. In the following description, the size of the first parasitic element **12***d* is defined as shown in FIG. **8**. Specifically, a length lp**1** refers to a length, extending in the x-axis direction, of the first parasitic element **12***d*, a width wp**1** refers to a length, extending in the y-axis direction, of the first parasitic element **12***d*, and a gap gap**1** refers to a gap between the stub **12***b* and the first parasitic element **12***d*.

According to the present Example, the shape of the first parasitic element **12***d* and the shape of the second parasitic element **12***e* are congruent with each other, and a gap between the stub **12***b* and the second parasitic element **12***e* is equal to the gap gap**1**.

(a) of FIG. **9** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized width wp**1**/λ obtained by normalizing the width wp**1** by a resonant wavelength λ (in the present Example, 5 mm) of a microstrip antenna is changed from 0.04 to 0.2 in increments of 0.04. (b) of FIG. **9** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **10** is a graph showing a fractional band width FBW of the antenna **1** and obtained in a case where the normalized width wp**1**/λ is changed from 0.04 to 0.2 in increments of 0.04. (b) of FIG. **10** is a graph showing a maximum gain of the antenna **1**. Note here that the fractional band width FBW means a ratio of a width of a band in which the reflection coefficient |S**11**| falls below −10 dB to the design center frequency of 60 GHz.

FIGS. **9** and **10** reveal that in a case where the normalized width wp**1**/λ is not less than 0.04 and not more than 0.2, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |S**11**| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz. Given that the fractional band width FBW exceeds 5% and the maximum gain exceeds 12 dBi, the normalized width wp**1**/λ can be said to have an optimum value of 0.04.

(a) of FIG. **11** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized length lp**1**/λ obtained by normalizing the length lp**1** by the resonant wavelength λ of the microstrip antenna is changed from 0.08 to 0.4 in increments of 0.04. (b) of FIG. **11** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **12** is a graph showing the fractional band width FBW of the antenna **1** and obtained in a case where the normalized length lp**1**/λ is changed from 0.08 to 0.4 in increments of 0.04. (b) of FIG. **12** is a graph showing the maximum gain of the antenna **1**.

FIGS. **11** and **12** reveal that in a case where the normalized length lp**1**/λ is not less than 0.08 and less than 0.3, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |S**11**| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz. Given that the fractional band width FBW reaches a maximum value and the maximum gain reaches a value close to the maximum value, the normalized length lp**1**/λ can be said to have an optimum value of 0.28.

(a) of FIG. **13** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized gap gap**1**/λ obtained by normalizing the gap gap**1** by the resonant wavelength λ of the microstrip antenna is changed from 0.004 to 0.02 in increments of 0.004. (b) of FIG. **13** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **14** is a graph showing the fractional band width FBW of the antenna **1** and obtained in a case where the normalized gap gap**1**/λ is changed from 0.004 to 0.02 in increments of 0.004. (b) of FIG. **14** is a graph showing the maximum gain of the antenna **1**.

FIGS. **13** and **14** reveal that in a case where the normalized gap gap**1**/λ is not less than 0.004 and not more than 0.02, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |S**11**| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz.

Further, FIGS. **13** and **14** also reveal that the fractional band width FBW exceeds 5% in a case where the normalized gap gap**1**/λ is not less than 0.004 and not more than 0.008. As a result of comparison between the normalized gap gap**1**/λ which is 0.004 and the normalized gap gap**1**/λ which is 0.008, the normalized gap gap**1**/λ which is 0.008 is more preferable. This is because the reflection characteristic has a peak near 60 GHz, and the peak has a simple shape. In view of the above description, the normalized gap gap**1**/λ can be said to have an optimum value of 0.008.

[Influence of Size of Third Parasitic Element on Characteristics]

The following description discusses, with reference to FIGS. **15** through **21**, an influence of a size of the third parasitic element **12***f* on characteristics of the antenna **1** in accordance with the present Example. In the following description, the size of the third parasitic element **12***f* is defined as shown in FIG. **15**. Specifically, a length lp**2** refers to a length, extending in the x-axis direction, of the third parasitic element **12***f*, a width wp**2** refers to a length, extending in the y-axis direction, of the third parasitic element **12***f*, and a gap gap**2** refers to a gap between the stub **12***b* and the third parasitic element **12***f*.

(a) of FIG. **16** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized width wp**2**/λ obtained by normalizing the width wp**2** by the resonant wavelength λ of the microstrip antenna is changed from 0.02 to 0.1 in increments of 0.02. (b) of FIG. **16** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **17** is a graph showing the fractional band width FBW of the antenna **1** and obtained in a case where the normalized width wp**2**/λ is changed from 0.02 to 0.1 in increments of 0.02. (b) of FIG. **17** is a graph showing the maximum gain of the antenna **1**.

FIGS. **16** and **17** reveal that in a case where the normalized width wp**2**/λ is not less than 0.02 and not more than 0.08, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |S**11**| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz. Given that the fractional band width FBW exceeds 5%, the normalized width wp**2**/λ is more preferably not less than 0.03 and not more than 0.06. Further, given that a band in which the reflection coefficient

|S11| falls below −15 dB is broad, the normalized width wp2/λ can be said to have an optimum value of 0.06.

(a) of FIG. **18** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized length lp2/λ obtained by normalizing the length lp2 by the resonant wavelength λ of the microstrip antenna is changed from 0.16 to 0.4 in increments of 0.04. (b) of FIG. **18** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **19** is a graph showing the fractional band width FBW of the antenna **1** and obtained in a case where the normalized length lp2/λ is changed from 0.16 to 0.4 in increments of 0.04. (b) of FIG. **19** is a graph showing the maximum gain of the antenna **1**.

FIGS. **18** and **19** reveal that in a case where the normalized length lp2/λ is 0.28, the antenna **1** exhibits a radiation characteristic of having the maximum gain which falls below 10 dBi at 60 GHz. In other words, FIGS. **18** and **19** reveal that in a case where the normalized length lp2/λ is not less than 0.16 and not more than 0.24, and not less than 0.32 and not more than 0.4, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |S11| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz.

From the viewpoint that the fractional band width FBW exceeds 4%, the maximum gain exceeds 12 dBi, and the antenna **1** is made smaller and integrated, the normalized length lp2/λ is preferably not less than 0.16 and not more than 0.24. Further, given that the fractional band width FBW exceeds 5%, the normalized length lp2/λ is more preferably not less than 0.2 and not more than 0.24.

As a result of comparison between the normalized length lp2/λ which is 0.2 and the normalized length lp2/λ which is 0.24, the normalized length lp2/λ which is 0.2 and the normalized length lp2/λ which is 0.24 are nearly equal in maximum gain, whereas the normalized length lp2/λ which is 0.24 is greater in fractional band width FBW than the normalized length lp2/λ which is 0.2. Thus, the normalized length lp2/λ can be said to have an optimum value of 0.24.

(a) of FIG. **20** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized gap gap2/λ obtained by normalizing the gap gap2 by the resonant wavelength λ of the microstrip antenna is changed from 0.004 to 0.02 in increments of 0.004. (b) of FIG. **20** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **21** is a graph showing the fractional band width FBW of the antenna **1** and obtained in a case where the normalized gap gap2/λ is changed from 0.004 to 0.02 in increments of 0.004. (b) of FIG. **21** is a graph showing the maximum gain of the antenna **1**.

FIGS. **20** and **21** reveal that in a case where the normalized length lp2/λ is in a range of not less than 0.004 and not more than 0.02, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |S11| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz.

Further, FIGS. **20** and **21** also reveal that the fractional band width FBW exceeds 5% in a case where the normalized gap gap2/λ is not less than 0.004 and less than 0.012. Thus, the normalized gap gap2/λ is more preferably not less than 0.004 and less than 0.012. In FIG. **20**, the normalized gap gap2/λ has an optimum value of 0.008.

[Influence on Characteristics of Width of Stub Provided at Terminal End]

The following description discusses, with reference to FIGS. **22** through **24**, an influence of a width of the stub **12*g*17** on characteristics of the antenna **1** in accordance with the present Example. The stub **12*g*17** is provided at the terminal end of the power feeding line **12*a***. In the following description, the width of the stub **12*g*17** is defined as shown in (a) of FIG. **22**. Specifically, a width wpt refers to a length, extending in the y-axis direction, of the stub **12*g*17**.

(a) of FIG. **23** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized width wpt/λ obtained by normalizing the width wpt by the resonant wavelength λ of the microstrip antenna is changed from 0.04 to 0.2 in increments of 0.04. (b) of FIG. **23** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **24** is a graph showing the fractional band width FBW of the antenna **1** and obtained in a case where the normalized width wpt λ is changed from 0.04 to 0.2 in increments of 0.04. (b) of FIG. **24** is a graph showing the maximum gain of the antenna **1**.

FIGS. **23** and **24** reveal that in a case where the normalized width wpt/λ is not less than 0.4 and not more than 0.2, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |S11| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz. Given that the fractional band width FBW exceeds 5%, the normalized width wpt/λ is more preferably not less than 0.08 and not more than 0.16.

[Influence of Sizes of Fourth Parasitic Element and Fifth Parasitic Element on Characteristics]

The following description discusses, with reference to FIGS. **22** and **25** through **28**, an influence of sizes of the fourth parasitic element **12*d*17** and the fifth parasitic element **12*e*17** on characteristics of the antenna **1** in accordance with the present Example. In the following description, the size of the fourth parasitic element **12*d*17** is defined as shown in FIG. (a) of FIG. **22**. Specifically, a length lpt refers to a length, extending in the x-axis direction, of the fourth parasitic element **12*d* 17**, and a gap gapt refers to a gap between the stub **12*g*17** and the fourth parasitic element **12*d*17**.

According to the present Example, the shape of the fourth parasitic element **12*d*17** and the shape of the fifth parasitic element **12*e*17** are congruent with each other, and a gap between the stub **12*g*17** and the fifth parasitic element **12*e*17** is equal to the gap gapt.

(a) of FIG. **25** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized length lpt/λ obtained by normalizing the length lpt by the resonant wavelength λ of the microstrip antenna is changed from 0.2 to 0.36 in increments of 0.04. (b) of FIG. **25** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **26** is a graph showing the fractional band width FBW of the antenna **1** and obtained in a case where the normalized length lpt/λ is changed from 0.2 to 0.4 in increments of 0.04. (b) of FIG. **26** is a graph showing the maximum gain of the antenna **1**.

FIGS. **25** and **26** reveal that in a case where the normalized length lpt/λ is not less than 0.2 and not more than 0.4, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |S11| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz. Given that the fractional band width FBW exceeds 5% and the maximum gain exceeds 12 dBi, the normalized length lpt/λ is preferably not less than 0.32 and not more than 0.4. In FIG. **25**, given that the fractional band width FBW has a maximum value, the normalized length lpt/λ is 0.36.

(a) of FIG. **27** is graphs each showing a reflection characteristic of the antenna **1**, the graphs being obtained in a case where a normalized gap gapt/λ obtained by normalizing the gap gapt by the resonant wavelength λ of the microstrip antenna is changed from 0.004 to 0.02 in increments of 0.004. (b) of FIG. **27** is graphs each showing a radiation characteristic, obtained on the y-z plane at 60 GHz, of the antenna **1**.

(a) of FIG. **28** is a graph showing the fractional band width FBW of the antenna **1** and obtained in a case where the normalized gap gapt/λ is changed from 0.004 to 0.02 in increments of 0.004. (b) of FIG. **28** is a graph showing the maximum gain of the antenna **1**.

FIGS. **27** and **28** reveal that in a case where the normalized gap gapt/λ is not less than 0.004 and not more than 0.02, the antenna **1** exhibits a reflection characteristic of having the reflection coefficient |**S11**| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz.

Further, FIGS. **27** and **28** also reveal that the fractional band width FBW exceeds 5% in a case where the normalized gap gapt/λ is not less than 0.004 and not more than 0.016.

[Influence of Presence or Absence of Parasitic Elements on Characteristics]

The following description discusses, with reference to FIGS. **22** and **29**, an influence of omission of the fourth parasitic element **12***d***17** and the fifth parasitic element **12***e***17** or addition of a sixth parasitic element **12***f* **17** on characteristics of the antenna **1** in accordance with the present Example.

(a) of FIG. **22** is a plan view of the antenna **1** in accordance with the present Example. (b) and (c) of FIG. **22** are plan views of antennas in accordance with Comparative Examples. The following description compares characteristics of a group of antennas listed below. Note that in each of the antennas illustrated in (a) through (c) of FIG. **22**, the antenna element provided between the input end and the terminal end of the power feeding line **12***a* includes the stub **12***b*, the first parasitic element **12***d*, the second parasitic element **12***e*, and the third parasitic element **12***f*.

An antenna E is the antenna **1** in accordance with the present Example (see (a) of FIG. **22**).

An antenna F is obtained by omitting the fourth parasitic element **12***d***17** and fifth parasitic element **12***e***17** in the antenna **1** in accordance with the present Example (see (b) of FIG. **22**).

An antenna G is obtained by newly adding the sixth parasitic element **12***f***17** in the antenna **1** in accordance with the present Example (see (c) of FIG. **22**).

(a) of FIG. **29** is graphs showing respective reflection characteristics of the antennas E through G. (b) of FIG. **29** is graphs each showing respective radiation characteristics, obtained on the y-z plane, of the antennas E through G. (a) and (b) of FIG. **29** reveal that the antennas E through G each exhibit a reflection characteristic of having the reflection coefficient |**S11**| which is not more than −10 dB in the operation band, and exhibits a radiation characteristic of having the maximum gain which is not less than 10 dBi at 60 GHz.

In a case where attention is paid to a width of a band in which the reflection coefficient |**S11**| is not more than −10 dB, it is revealed that the antennas E through G have respective band widths that are nearly equal to each other, and the antenna E has the greatest band width. Meanwhile, in a case where attention is paid to a width of a band in which the gain is not less than 10 dBi, it is revealed that the antenna E has the greatest band width. In view of the above, it is revealed that the antenna E is most optimally arranged of the antennas E through G. Specifically, the antenna **1** in accordance with the present Example which antenna **1** is arranged to include the fourth parasitic element **12***d***17** and the fifth parasitic element **12***e***17** is preferable.

[Conclusion]

In order to attain the object, a microstrip antenna in accordance with the present embodiment includes: a dielectric substrate; a comb-line antenna conductor provided on a front surface of the dielectric substrate and including: a power feeding line that extends in a first direction; and a stub that extends from the power feeding line in a second direction orthogonal to the first direction; a ground conductor provided on a back surface of the dielectric substrate; a first parasitic element provided on the front surface of the dielectric substrate and facing a first side of the stub which first side is on a side of a direction opposite to the first direction; and a second parasitic element provided on the front surface of the dielectric substrate and facing a second side of the stub which second side is on the first direction side.

According to the arrangement, functions of the first parasitic element and the second parasitic element make it possible to expand a width of a band in which an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic are exhibited.

The microstrip antenna in accordance with the present embodiment is preferably arranged to further include: a third parasitic element provided on the front surface of the dielectric substrate and facing a third side of the stub which third side is on the second direction side.

The arrangement makes it possible to further expand a width of a band in which an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic are exhibited.

The antenna in accordance with the present embodiment is preferably arranged such that the stub has a root provided with a slit that extends from the second side in a direction opposite to the first direction.

The arrangement makes it possible to obtain a more excellent reflection characteristic and a more excellent radiation characteristic.

The antenna in accordance with the present embodiment is preferably arranged to further include: a waveguide joined to the back surface of the dielectric substrate and having: a tube axis orthogonal to the back surface of the dielectric substrate; and a tube wall whose end surface surrounds an opening provided in the ground conductor; a shield provided on the front surface of the dielectric substrate and provided with a slit in which to provide an input end of the power feeding line; and short-circuit parts via which the ground conductor and the shield are to be short-circuited and which are through the dielectric substrate, the short-circuit parts being provided around an entire outer circumference of the shield except for a place where the slit is provided, and the slit having a reverse taper shape that has a greater width in an inner part of the slit.

The arrangement makes it possible to obtain a more excellent reflection characteristic and a more excellent radiation characteristic.

The antenna in accordance with the present embodiment is preferably arranged such that: the first parasitic element has a length that extends in the first direction and is equal to a length, extending in the first direction, of the second parasitic element; and wp1/λ is not less than 0.04 and not more than 0.2 where wp1 is the length, extending in the first direction, of the first parasitic element and λ is a resonant wavelength of the microstrip antenna.

The antenna in accordance with the present embodiment is preferably arranged such that: the first parasitic element has a length that extends in the second direction and is equal to a length, extending in the second direction, of the second parasitic element; and lp1/λ is not less than 0.08 and less than 0.3 where lp1 is the length, extending in the second direction, of the first parasitic element and λ is a resonant wavelength of the microstrip antenna.

The antenna in accordance with the present embodiment is preferably arranged such that: a gap between the stub and the first parasitic element and a gap between the stub and the second parasitic element are equal to each other; and gap1/λ is not less than 0.004 and not more than 0.02 where gap1 is the gap between the stub and the first parasitic element and λ is a resonant wavelength of the microstrip antenna.

The antenna in accordance with the present embodiment is preferably arranged such that wp2/λ is not less than 0.02 and not more than 0.08 where wp2 is a length, extending in the first direction, of the third parasitic element and λ is a resonant wavelength of the microstrip antenna.

The antenna in accordance with the present embodiment is preferably arranged such that lp2/λ is not less than 0.16 and not more than 0.24, or not less than 0.32 and not more than 0.4 where lp2 is a length, extending in the second direction, of the third parasitic element and λ is a resonant wavelength of the microstrip antenna.

The antenna in accordance with the present embodiment is preferably arranged such that gap2/λ is not less than 0.004 and not more than 0.02 where gap2 is a gap between the stub and the third parasitic element and A is a resonant wavelength of the microstrip antenna.

The arrangements each make it possible to further expand a width of a band in which an ever-more-excellent reflection characteristic and an ever-more-excellent radiation characteristic are exhibited.

[Additional Matter]

The present invention is not limited to the description of the embodiments (examples) above, but may be altered by a skilled person within the scope of the claims. An embodiment based on a proper combination of technical means disclosed in different embodiments is encompassed in the technical scope of the present invention.

INDUSTRIAL APPLICABILITY

The present invention can be suitably used as, for example, an antenna that operates in a millimeter wave band.

REFERENCE SIGNS LIST

1 Antenna
11 Dielectric substrate
12 Antenna conductor
12*a* Power feeding line
12*b*1-12*b*16 Stub
12*c* Slit
12*d*1-12*d*16 First parasitic element
12*e*1-12*e*16 Second parasitic element
12*f*1-12*f*16 Third parasitic element
12*d* 17 Fourth parasitic element
12*e*17 Fifth parasitic element
12*g*17 Stub
13 Ground conductor
13*a* Opening
14 Waveguide
14*a* Tube wall
14*b* Cavity
15 Shield
15*a* Slit
16 Short-circuit part

The invention claimed is:

1. A microstrip antenna comprising:

a dielectric substrate:

a comb-line antenna conductor provided on a front surface of the dielectric substrate and including: a power feeding line that extends in a first direction; and a stub that extends from the power feeding line in a second direction orthogonal to the first direction;

a ground conductor provided on a back surface of the dielectric substrate;

a first parasitic element provided on the front surface of the dielectric substrate and facing a first side of the stub which first side is on a side of a direction opposite to the first direction; and

a second parasitic element provided on the front surface of the dielectric substrate and facing a second side of the stub which second side is on the first direction side.

2. The microstrip antenna as set forth in claim **1**, further comprising:

a third parasitic element provided on the front surface of the dielectric substrate and facing a third side of the stub which third side is on the second direction side.

3. The microstrip antenna as set forth in claim **1**, wherein the stub has a root provided with a slit that extends from the second side in a direction opposite to the first direction.

4. The microstrip antenna as set forth in claim **1**, further comprising:

a waveguide joined to the back surface of the dielectric substrate and having: a tube axis orthogonal to the back surface of the dielectric substrate; and a tube wall whose end surface surrounds an opening provided in the ground conductor;

a shield provided on the front surface of the dielectric substrate and provided with a slit in which to provide an input end of the power feeding line; and

short-circuit parts via which the ground conductor and the shield are to be short-circuited and which are through the dielectric substrate,

the short-circuit parts being provided around an entire outer circumference of the shield except for a place where the slit is provided, and the slit having a reverse taper shape that has a greater width in an inner part of the slit.

5. The microstrip antenna as set forth in claim **1**, wherein:

the first parasitic element has a length that extends in the first direction and is equal to a length, extending in the first direction, of the second parasitic element; and

wp1/λ is not less than 0.04 and not more than 0.2 where wp1 is the length, extending in the first direction, of the first parasitic element and λ is a resonant wavelength of the microstrip antenna.

6. The microstrip antenna as set forth in claim **1**, wherein: the first parasitic element has a length that extends in the second direction and is equal to a length, extending in the second direction, of the second parasitic element; and

lp**1**/λ is not less than 0.08 and less than 0.3 where lp**1** is the length, extending in the second direction, of the first parasitic element and λ is a resonant wavelength of the microstrip antenna.

7. The microstrip antenna as set forth in claim **1**, wherein: a gap between the stub and the first parasitic element and a gap between the stub and the second parasitic element are equal to each other; and

gap**1**/λ is not less than 0.004 and not more than 0.02 where gap**1** is the gap between the stub and the first parasitic element and λ is a resonant wavelength of the microstrip antenna.

8. The microstrip antenna as set forth in claim **2**, wherein wp**2**/λ is not less than 0.02 and not more than 0.08 where wp**2** is a length, extending in the first direction, of the third parasitic element and λ is a resonant wavelength of the microstrip antenna.

9. The microstrip antenna as set forth in claim **2**, wherein lp**2**/λ is not less than 0.16 and not more than 0.24, or not less than 0.32 and not more than 0.4 where lp**2** is a length, extending in the second direction, of the third parasitic element and λ is a resonant wavelength of the microstrip antenna.

10. The microstrip antenna as set forth in claim **2**, wherein gap**2**/λ is not less than 0.004 and not more than 0.02 where gap**2** is a gap between the stub and the third parasitic element and λ is a resonant wavelength of the microstrip antenna.

* * * * *